

DEVELOPMENT OF ARROWROOT, LESSER YAM AND POTATO BASED EXTRUDED PRODUCTS

**A Thesis submitted to
DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI – 415712.
Maharashtra State (India)**

In the partial fulfillment of requirements for degree

of

**MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)**

in

PROCESSING AND FOOD ENGINEERING

by

Navale Surekha Ashok

(Reg. No. – ENDPM 13/076)

B.Tech (Agril. Engg.)



**DEPARTMENT OF AGRICULTURAL PROCESS ENGINEERING
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
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DAPOLI – 415712. DIST. – RATNAGIRI. M.S. (INDIA)**

SEPTEMBER 2015

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Approved by

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Associate Professor of APE
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SEPTEMBER 2015

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part thereof has not been submitted
by me or any other person to any other
University or Institute
for a Degree or
Diploma.

Place: CAET, Dapoli

Dated: / / 2015

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CERTIFICATE

This is to certify that the thesis entitled, **“DEVELOPEMENT OF ARROWROOT, LESSER YAM AND POTATO BASED EXTRUDED PRODUCTS”** submitted to the Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri (Maharashtra State) in partial fulfillment of the requirement of award of degree of **Master of Technology (Agricultural Engineering)** in **Processing and Food Engineering**, embodies the result of piece of bonafied research work carried out by **Miss. Navale Surekha Ashok** (Reg. No.– ENDPM 13/076) under my guidance and supervision. The Result embodies in this project report has not been submitted to any other university or institute for the award of degree or diploma.

The assistance and help received during the course of this project work and sources of the literature have been duly acknowledged.

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CERTIFICATE

This is to certify that the thesis entitled, **“DEVELOPEMENT OF ARROWROOT, LESSER YAM AND POTATO BASED EXTRUDED PRODUCTS”** submitted to the Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri (Maharashtra State) in the partial fulfillment of the requirements for the award of the degree of **Master of Technology (Agricultural Engineering)** in **Processing and Food Engineering**, embodies the record of a piece of bonafied research work carried out by **Miss. Navale Surekha Ashok** under the guidance and supervision of **Dr. S. B. Swami**, Associate Professor, Department of Agricultural Process Engineering, C.A.E.T. Dapoli. No part of the thesis has been submitted for any other degree, diploma or publication in any other form.

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Date: / / 2015

Dean

Faculty of Agricultural Engineering

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Date : / / 2015

(S. A. Navale)

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LIST OF SYMBOLS

Symbols	Description
$^{\circ}\text{C}$	Degree Celsius
kg	Kilogram
m^3	Cubic meters
g	Gram
%	Per cent
cm	Centimeter
$\pm$	Plus minus
mm	Milliliter
min	Minute
ml	Milliliter
h	Hour
s	Second
$\times$	Multiplication
W/m^2	Watt per meter square
MC	Moisture content
\$	Doller
$\leq$	Less or greater than equal to
$<$	Less or equal than
/	Per
=	Equal to
N	Newton
μ	Micron
L	Lightness
a	Redness
b	Yellowness
mg	Milligram
$^{\circ}\text{B}$	Degree brick
T	Treatments
L/D	Length to diameter

LIST OF ABBREVIATIONS

Abbreviations	Meanings
ANOVA	Analysis of Variance.
AOAC	Association of Official Analytical Chemists
APE	Agricultural Process Engineering
Avg.	Average
CAET	College of Agricultural Engineering and Technology
CD	Coefficient of determination
Db	Dry basis
DBSKKV	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth
Dept.	Department
Df	Degree of freedom
Engg.	Engineering
<i>et al.</i>	and others
etc.	et cetera
Exp	Exponential
Fig.	Figure
i.e.	that is
J.	Journal
MC	Moisture content
YI	Yellowness Index
MS	Mean square
MSS	Mean sum of square
NAIP	National Agricultural Innovation Project
TR	Texturized Rice
Rpm	revolution per minute
SAS	Statistical analysis software
SS	Sum of square
SV	Source of variation
Vol.	Volume
w.r.t.	With respect to
Wb	Wet basis
Eq.	Equation

Abbreviations	Meanings
FW	Fresh weight
WAI	Water absorption index
WAC	Water absorption capacity
OAC	Oil absorption capacity
WSI	Water solubility index
HR	Hardness
SE	Standard error
w/w	Weight by weight
RTE	Ready-to-eat
SS	Screw speed
BT	Barrel temperature
FMC	Feed moisture content
US	Union standards
HTST	High temperature short time
SME	Specific mechanical energy
LEI	Longitudinal expansion index
MER	Mass flow rate
SEI	Sectional expansion index
S	Screw speed
T	Temperature
ER	Expansion ratio
BD	Bulk density
HR	Hardness
SL	Specific length
F	Variance ratio
F1, F2, F3, F4, F5, F6, F7, F8 and F9	Treatments for flour compositions
T1, T2, T3, T4, T5 and T6	Treatments for extrusion
p	Probability at 1% or 5% level of significant
ER1, ER2, ER3, ER4, ER5 and ER6	Expansion ratio for treatments T1, T2, T3, T4, T5 and T6
BD1, BD2, BD3, BD4, BD5	Bulk density for treatments T1, T2, T3, T4, T5 and T6

Abbreviations	Meanings
and BD6	
WAI1, WAI2, WAI3, WAI4, WAI5 and WAI6	Water Absorption Index for treatments T1, T2, T3, T4, T5 and T6
WSI1, WSI2, WSI3, WSI4, WSI5 and WSI6	Water Solubility Index for treatments T1, T2, T3, T4, T5 and T6
HR1, HR2, HR3, HR4, HR5 and HR6	Hardness for treatments T1, T2, T3, T4, T5 and T6

ABSTRACT

DEVELOPMENT OF ARROWROOT, LESSER YAM AND POTATO BASED EXTRUDED PRODUCTS

by

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In the present research work, “Development of Arrowroot, Lesser yam and Potato based extruded products” was done from tuber crops i.e. arrowroot, lesser yam and potato flours at extrusion temperature 130, 150 and 170°C and screw speed 330, 360 and 390 rpm. Preparation of flour from this tuber crops by using the convective hot air dryer (tray dryer) at 60°C. The drying kinetics of arrowroot, lesser yam and potato slices in terms of moisture content verses drying time and moisture content verses drying rate was investigated. A convective hot air dryer (tray dryer) were employed to study the drying behavior at 60°C. The arrowroot, lesser yam and potato tuber crop slices were dried from an initial moisture content of 124.42% (db) to 7.61% (db); 361.71% (db) to 9.56% (db) and 243.85% (db) to 6.10% (db) respectively. It took around 8.25 h, 7.75 h and 9.25 h for drying of arrowroot, lesser yam and potato respectively by tray drying at 60°C. Physicochemical and functional properties of flours extracted from arrowroot, lesser yam and potato were investigated. Examination of the functional properties of prepared flours from arrowroot, lesser yam and potato blend in the ratio of 100:00:00, 00:100:00, 00:00:100, 00:50:50, 10:40:50, 20:30:50, 30:20:50, 40:10:50 and 50:00:50 respectively were carried out. The nutritional properties of the flour combinations e.g. protein 2.27-5.36%, fat 0.23-0.98%, fiber 0.48-3.86%, ash 1.91-4.14%, moisture content 5.81-8.56% and carbohydrates 79.81-86.66% respectively. The functional properties of the flour combinations e.g. water absorption capacity 1.36-2.46ml/g, oil absorption capacity 0.63-1.56ml/g, bulk density 2.41-4.31g/cm³, flour dispersibility 24.33-41.33% and yellowness index 21.81-32.16 respectively.

Extrusion cooking has been carried out at extrusion temperature 130, 150 and 170°C, screw speed 330, 360 and 390 rpm and flour combinations of Arrowroot flour, Lesser yam flour and Potato flours. Potato flour has been taken as base flour 50% and rest of the two flours varied i.e. Arrowroot flours were (0, 10, 20, 30, 40 and 50%) and Lesser yam flour (50, 40, 30, 20, 10 and 0%). These three flour combinations at 10% MC (db) were extruded using twin screw extruder at screw speed 330, 360 and 390 rpm and barrel temperature 130, 150 and 170°C. The extrudates were analyzed for its functional properties (water absorption index, water solubility index, expansion ratio, bulk density and hardness) and physico-chemical properties (moisture content, protein, fat, crude fibre, ash content, carbohydrates and colour). The sensory analysis of the developed extrudates was performed through a panel of 45 trained judges for all 54 samples. The extrudates were optimized for its desirable better functional and nutritional properties (like lower bulk density, more expansion ratio, lower hardness; protein, fat, fibre, ash and carbohydrates). The optimum extrudates combination was observed at flour combination (Arrowroot:Lesser yam:Potato as 10:40:50) at screw speed 385-390 and temperature 130-135°C. The functional properties at optimum zone was bulk density 0.15 g/cm³, expansion ratio 3.10, hardness 1460g, water absorption index 4.22g/g and water solubility index 31.30% respectively. The nutritional properties at optimum zone was protein 2.80%, fat 1.40%, ash 1.96%, carbohydrates 85.01%, fibers 1.20% and moisture content 6.0 % (db) respectively. The sensory score was highest at Arrowroot: Lesser yam: Potato (10:40:50) at 390 rpm screw speed and 130°C temperature. The sensory properties at the optimum zone i.e. appearance 7.5, colour 7.2, taste 8.5, texture 7.4, crispiness 7.0, expansion 7.3 and overall acceptability 7.5 respectively.

The extrudates prepared at optimum combination from (arrowroot (10%), lesser yam (40%) and potato (50%)) with twin screw extruder at extrusion temperature 130°C, screw speed 390 rpm and 10% moisture (7ml water:3ml Kokum Liquid Concentrate)) were used for the packaging and storage study of the extrudates. The 60 g extrudates were packed in 3 types of packaging materials i.e. aluminium foil pouch (50 µ), polyethylene pouch (100 µ) and polyester pouch (40 µ) and stored at ambient temperature up to 60 days. Then stored samples were evaluated at interval of 0, 10, 20, 30, 40, 50 and 60 days for nutritional properties like protein, fat, fiber, ash, moisture, carbohydrates and functional properties like expansion ratio, bulk density, water absorption index, water solubility index, hardness in order to study the storage stability of the product. It was revealed that there is no significant ($p \leq 0.01$) effect of packaging material and storage durations on nutritional and functional properties of stored extrudates. Among the packaging materials studied aluminium foil pouch (50 µ) was the best

packaging material to store the extrudates up to 60 days. The change in nutritional properties of the extrudates over original properties at the 60 days period in aluminium foil pouch were protein 0.1 %, fat 0.18 %, fiber 0.14 %, ash 0.13 %, carbohydrates 1 % and moisture 0.83 %. The change in functional properties of the extrudates over the original properties at 60 days period packed in the aluminium foil pouch is expansion ratio 0.04, bulk density 0.06 g/cm³, water absorption index 0.31 g/g, water solubility index 11.37 %, and hardness of extrudates 198 g respectively. Extrudates can be stored in good condition in aluminium foil pouch up to 2 months with better retention of nutritional and functional properties.

(Keywords: Arrowroot, Lesser yam, Potato, Drying of tuber crops, Extrusion cooking, Nutritional and functional properties, Tuber flour, extrudates, Sensory analysis, Optimization of extrudates, Packaging, Storage.)

I. INTRODUCTION

Tropical roots and tuber crops are considered as the third important crops after cereals and grain legume. They contribute 6% of the average daily calorific intake of human beings. The tropical roots and tuber crops (cassava, sweet potato, yams and aroids) are of utmost importance for the world food security. The popular tuber crops include sweet potato (*Ipomoea batatas*), cassava (*Manihot esculenta*), taro (*Colocasia esculenta*), yam (*Dioscorea* sp.), elephant foot yam (*Amorphophallus paeoniifolius*), yam bean (*Pachyrrhizus erosus*), arrowroot (*Maranta arundinaceae*), etc constitute cheap source of food and energy particularly suitable for the poor section of human population and capable enough to withstand biotic and abiotic stresses (Lenka *et al.*, 2012).

Arrowroot (*Marantha arundinacea*) is a tropical plant that grows in warm, swampy areas. The plant originated from the caribbean region but is now widespread throughout the tropics. It is an under exploited tuber crops having tremendous potential in food and pharmaceutical industries. The tuber contains about 10% to 25% extractable starch, which from a nutritional point of view is the richest (unenriched) natural starch on the earth (Spennemann, 1992). The starch granules having round, polygonal shape and the amylase content ranges between 16-27%. It is popular for its high digestibility and medicinal properties. The starch is often used as a thickner in all kinds of foods, dressings, soups, sauces, candies, cookies and desserts. It posses demulcent properties soothes and protects irritated or inflamed internal tissues of the body and hence is given in bowel complaints (Mathew, 2007). Arrowroot is used as an article of diet in the form of biscuits, puddings, jellies, cakes and hot sauces and so on, and an early digestible food for children and peoples with dietary restrictions. Lack of gluten in arrowroot starch makes it added as a replacement of wheat flour in baking (Jyothi, 2009).

Yam (*Dioscorea Spp*) is a traditional food crop of great antiquity that originated in Africa, Asia and America and is now widely distributed throughout the tropics, with a few members occurring in temperate zone (Coursey, 1983). Yams are generally baked, boiled, fried in oil or cooked in stews in similar manner to the potato (O' Hair, 1990). *Dioscorea esculenta* (Lour) Burk is least studied of major staple yam species, although it is widely cultivated in southern Asia and the pacific and is the dominant or co-dominant staple food in parts of India and Papua New Guinea (O'Sullivan and Ernest, 2007). They belong to the *Dioscorea* genus, which includes 600 spices. Coursey (1967) and Leon (1977) mentioned

four distinct centres of origin for the edible yam. World yam production is about 38×10^6 tonnes per year (FAO, 2002). Yam serves as a major source of income in countries where they are cultivated. Yam tubers are usually processed into flour by peeling, slicing, parboiling in hot water (40-60°C for 1-3 h), soaking and sun drying (Onayemi and Potter, 1974). Despite the high levels of yam production noted, it contains high amount of starch (70-80% (db)), these starch resource is not used for starch production on an industrial level (Amani *et al.*, 2004).

Potato grown in 150 countries is the most important food crop in the world after wheat, rice and maize. It is high yielding short duration crop. The potato ease of cultivation and good nutrient content has made it a valuable cash crop for millions of farmers. India is a second largest potato producer in the world and produced 37.3 million tons of potato during 2009-10 (Singh *et al.*, 2011). Once harvested, potato can be used for variety of purposes as a fresh vegetable for cooking, a raw material for processing into food products, food ingredients, starch and alcohol, as a feed for animals and seed tubers for growing the next season's crop. With phenomenal increase in potato production, recurring gluts have become common in country. Prices crash drastically during the harvesting months leading to panic scale by the farmers and inturn leading to heavy monetary losses. Sometimes, farmers are not able to even cover their cost of production.

Drying is a complex operation involving transient transfer of heat and mass along with several rate processes such as physical or chemical transformation, which in turn may cause changes in product quality as well as the mechanisms of heat and mass transfer. The physical changes that may occur include: shrinkage, puffing, crystallization and glass transition. Drying is one of the oldest and most widely used methods of food preservation. It is a method in which moisture content of fruits and vegetables are decreased by heated air to minimize biochemical, chemical and microbiological deterioration. When a wet solid is subjected to thermal drying, two processes occur simultaneously; transfer of energy (most of heat) from the surrounding environment to evaporate the surface moisture and transfer of internal moisture to the surface of the solid and its subsequent evaporation due to the first process (Ojediran and Raji, 2010). It brings about substantial reduction in weight and volume, minimizing packing, storage and transportation costs and enables storability of the product under ambient temperatures (Sacilik, 2007).

Various researchers have reported the drying characteristics. Drying characteristics reported for yam, potato and carrot, sweet potato, tigernut etc. (Kafilat, 2010; Srikiatden and

Roberts, 2008; Jimoh *et al.*, 2009; Seidu *et al.*, 2012; Dagde *et al.*, 2014; Oladele and Aina, 2007).

The functional properties of flours i.e. bulk density, water absorption capacity, oil absorption capacity are the intrinsic physicochemical characteristics which may affect the behavior of food systems during storage (Shobha *et al.*, 2012). Water absorption capacity is an important functional characteristic in the development of ready to eat food from cereal grains and high water absorption capacity may assure product cohesiveness (Shobha *et al.*, 2007). The higher dispersibility of meal in water indicated its ability to reconstitute (Jolaoso *et al.*, 2012). Bulk density is a function of the particle size and low bulk density is an advantage when used as a weaning food (Ukwuru, 2003). Bulk density is generally affected by the particle size and density of the flour and it is very important in determining the packaging requirement, material handling and application in wet processing in the food industry (Karuna *et al.*, 1996). The oil absorption capacity is a critical assessment of flavor retention and increases the palatability of foods (Shobha *et al.*, 2007). Oil absorption index is important since oil acts as flavor retainer and increase the mouth feel of foods, improvement of palatability and extension of shelf life particularly in bakery or meat products where fat absorptions are desired (Aremu *et al.*, 2007). Color is one of the important physical parameters often used by the manufacturers and consumers to qualitatively assess the eminence of food products (Kaur *et al.*, 2014).

Extrudates snacks are generally made from grain based raw materials. Potato offers very large starch granules that break down easily with definite flavor, excellent swelling and binding power and could be best utilized for making extruded snack products because of their specific properties like improved taste, texture, gelatinization and shelf life, which influence the higher expansion, natural taste and better crispiness of the end product.

One of the most important technology, which have shows great potential for the development of new snack products is extrusion cooking. Extrusion is a continuous food processing technique classified as a high temperature short time (HTST) operation in which raw food materials are thermo-mechanically cooked in a screw barrel assembly by a combination of moisture, pressure and temperature in order to be mechanically sheared and shaped (Riaz, 2001). It is a low cost and efficient technology that utilizes high temperature, pressure and shear force to produce highly expanded, low density snacks with unique textural properties. Product quality can vary considerably depending on the extrusion variables such as feed composition, screw speed, temperature profile in the barrel, feed moisture, feed

particle size, feed rate and die geometry. Extruder type and chemical composition of raw materials also affect product characteristics. These material and process variables determines the extent of macromolecular transformations during extrusion, which inturn influences the rheological properties of food melt in the extruder and consequently, the product characteristics of extrudates. Physical characteristics such as expansion, density, hardness are important parameters to evaluate the consumer acceptability of the final product (Patil *et al.*, 2007).

The effect of ingredient properties and processing conditions (such as feed moisture content, screw speed and barrel temperature) on final product quality are also reflected by their influence on process responses or extruder system such as motor torque, die pressure, product temperature and specific mechanical energy (SME).

Extensive work has been done by many researchers on extrusion of cereals such as rice, wheat and corn (Dahlin and Lorenz, 1993; Eerlingen *et al.*, 1994; Chaudhari and Gautam, 1999; Bryant *et al.*, 2001; Pathania *et al.*, 2013a). However, relatively less work has been done on the extrusion of tubers, their flours and starches.

Badrie and Mellows (1991a, 1991b) have studied the influence of variables on the expansion characteristics, texture and microstructure of cassava flour extrudates. The influence of extruder and processing parameters on the characteristics of cassava flour extrudates was studied by Sheriff (1996). Iwe *et al.*, 2000 studied the extruded blends of defatted soy flour and sweet potato flour in a single screw extruder at varying pre-set rotational speeds and their results showed that the whiteness of the extrudates decreased with increase in sweet potato in the blends during extrusion. Taro flour, derived from the corm of *cotocasia esculenta* cv. Lehua, was extruded with whey protein concentrate, whey protein isolate or lactalbumin to derive high protein blends for incorporation in some weaning foods.

The packaging of food is one of the prime requisites to improve and monitor the producer to consumer food production system. It forms an integral part of manufacturing process providing the link between the processor and the consumer. In fact, it plays a dominant role in the total food manufacturing activity and in marketing sector. Snack food have to be packed in attractive packaging so as to be given impression of wholesomeness and freshness to increase sales appeal and it should be hygienic. With growing concern of diet, weight control and general health, government bodies are recommending to the peoples and making a conscious effort to eat healthier, natural snacks such as fruit, vegetable, nuts and cereal grains while avoiding high-calorie, low-calorie nutrient junk food (Saurabh *et al.*, 2013). Packaging is a means of providing the correct environmental conditions for food

during storage and the choice of materials for packaging depends on the nature of the product, storage duration and handling conditions (temperature, humidity, risk of physical deterioration) and other environmental factors (Daramola *et al.*, 2010). To store extrudates for maximum period, it requires good packaging material to extend the shelf life of the extrudates by better protection from hazards during storage.

Despite its application in many fields of food industry, no systematic study has been undertaken so far on extrusion cooking on blends as Potato, Lesser yam and Arrowroot flour. Considering the economic importance of Potato, Lesser yam and Arrowroot and its special properties suited for food industry. Potato has the more nutritive value as that fetching less price. Arrowroot and Lesser yam is seasonally available tuber crop in konkan region and can be used for development of extrudates as a value added processed product. In the present study, it is proposed to develop Arrowroot, Lesser yam and Potato based value added product using extrusion cooking technology. Therefore by considering all above point's present study is undertaken with following objectives:

1. To determine the Physico-chemical properties of material used.
2. To study the influence of composition and extrusion parameters on the extrudates.
3. To study the packaging and storage of extrudates.

II. REVIEW OF LITERATURE

This section deals with the literature reviewed pertaining to different aspects of extrusion as a process and technology. Studies conducted by researchers in India and abroad have been reviewed for the different aspects of extrusion process and the material extruded product. The review was undertaken for different tuber crops, grains, cereals, used for extrusion and its composition, flour formulation, extrusion cooking technology, parameters affecting extrusion, nutritional and sensory properties of extruded product and development of value added products from arrowroot, lesser yam and potato tuber crops.

2.1 Tuber crops production status, its composition and functional properties.

Wheatley *et al.*, (1995) studied the production trends, nutritional composition of roots and tuber crops and reported the nutritional composition of tuber crops. Table 2.1 shows the production and nutrition composition of roots and tuber crops and 2.2 shows the nutritional characteristics of roots and tubers.

Table 2.1: Production and Nutritional composition of a 100 g edible portion of root and tuber crops

Food	Production (000 t)	Water (%)	Protein (g)	Energy (kcal)	Fat (g)	Ash (mg)	Ca (mg)	P (mg)	Fe (mg)	Na (mg)
Cassava	149,193	36	0.9	124	0.1	0.6	-	-	-	-
Sweet potato	122,057	71	1.7	114	0.4	1.0	32	47	0.7	10
Potato	79, 066	80	2.1	76	0.1	0.9	7	53	0.6	3
Yam	18,083	74	2.1	101	0.2	1.0	20	69	0.6	-

(Root and tuber crops does not include peel)

Table 2.2: Nutritional characteristics of roots and tubers

Nutrients	Cassava ¹	Potato ¹	Sweet potato ¹	Yam ¹	Arrowroot
Dry matter (%)	30–40	20	19–35	20–42	-
Starch (%FW)	27–36	13–16	18–28	18–25	23
Total sugars (%FW)	0.5–2.5.	0–2.0	1.5–5.0	0.5–1.0	-
Protein (%FW)	0.5–2.0	2.0	1.0–2.5	2.5	5.6
Fat (%)	0.2	0.5	-	0.5	0.23
Fiber (%FW)	1.0	0.5	1.0	0.6	4.4
Ash (% FW)	0.5–1.5	1.0–1.5	1.0	0.5–1.0	-

((Wheatley *et al.*, 1995; Bradbury and Holloway, 1988)¹).

Ilo *et al.*, (2000) studied the role of lipid in extrusion cooking process. Expanded (Ready to Eat) RTE cereals are manufactured from mixtures of cereal flours and starches combined with small amounts of malt, fat, sugars, emulsifiers and salt. The raw materials in the extrusion cooking processes cover various combinations of ingredients including: cereals, grains and starches, tubers, legumes, oil seeds, cereals as well as animal fat and proteins.

Odebunmi *et al.*, (2007) studied the nutritional composition of selected tuber and root crops used in Nigerian food preparations. The proximate composition and mineral concentration of tubers and root crops were studied. The proximate composition of tuber crops studied which include white yam, cocoyam, water yam, cassava, sweet potato, potato and root crops include onion, garlic, ginger, carrot were determined. Proximate composition of potato crop is shown in Table 2.3.

Table 2.3: Proximate composition of potato tuber crop.

Constituents	Potato
Moisture (%)	78.90
Dry matter (%)	21.90
Ash (%)	1.45
Crude protein (%)	4.74
Crude fat (%)	0.71
Crude fibre (%)	0.77
Total carbohydrate (%)	14.20

(Odebunmi *et al.*, 2007)

Jyothi, (2009) gives the information about arrowroot tuber crop. Arrowroot (*Marantha arundinacea*) is a tropical plant that grows in warm, swampy areas. The plant originated from the caribbean region but is now widespread throughout the tropics. It is an under exploited tuber crops having tremendous potential in food and pharmaceutical industries. The tuber contains about 10% to 25% extractable starch, which from a nutritional point of view is the richest (unenriched) natural starch on the earth (Spennemann, 1992). The starch granules are while having round, polygonal shape and the amylase content ranges between 16-27%. It is popular for its high digestibility and medicinal properties. The starch is often used as a thickner in all kinds of foods, dressings, soups, sauces, candies, cookies and desserts. It posses demulcent properties soothes and protects irritated or inflamed internal tissues of the body and hence is given in bowel complaints (Mathew, 2007). Arrowroot is used as an article of diet in the form of biscuits, puddings, jellies, cakes and hot sauces and so on, and an early digestible food for children and peoples with dietary restrictions. Lack of gluten in arrowroot starch makes it added as a replacement of wheat flour in baking.

Ukpabi, (2010) studied the chemical composition of lesser yam tuber crop and reported that percent protein, fat, fiber, ash and carbohydrates i.e. 6.15%, 1.00%, 1.5%, 2.05% and 79.54% respectively.

Adeleke and Odedeji (2010) studied the functional properties of wheat and sweet potato flour blends. They studied the functional properties like swelling power, viscosity, pH, water absorption capacity, fat absorption capacity, foaming capacity, foaming stability and bulk density of wheat and sweet potato tuber flour blends were investigated. The swelling power for wheat flour was 12.75% which was greater than that of sweet potato flour of 5.73%, Wheat flour recorded the highest foaming capacity of 4.12% while sweet potato flour had 1.28%, The pH values for other blends ranged between 5.40 and 5.70 as more and more sweet potato flour was added to wheat flour the pH value was tending toward slight acidity, Bulk density value for wheat flour was 7.47 g/cm³ while sweet potato flour recorded 6.83 g/cm³.

Adegunwa *et al.*, (2011) studied the effect of processing on the nutritional contents of yam and cocoyam tubers. Two species of water yam and white yam were subjected to various processing methods i.e. boiling, sun drying and roasting. The proximate, chemical and pasting properties of the processed yams were determined. The results showed that the moisture content ranged from 5.01 to 5.02%, ash content from 1.88 to 5.50%, fat content from 0.24 to 0.75%, protein content from 0.03 to 5.02%, amylase content from 23.35 to 33.82%, sugar content 2.13 to 7.59% and starch content from 62.94 to 93.67%.

Singh *et al.*, (2011) gives the information about potato. Potato grown in 150 countries is the most important food crop in the world after wheat, rice and maize. It is high yielding short duration crop. The potato ease of cultivation and good nutrient content has made it a valuable cash crop for millions of farmers. India is a second largest potato producer in the world and produced 37.3 million tons of potato during 2009-10.

Babu and Parimalavalli (2012) studied the functional and chemical properties of starch isolated from tubers (Elephant Foot Yam; Cush-Cush Yam). They studied the functional properties like water absorption capacity, oil absorption capacity and swelling capacity and chemical properties such as moisture content and dry matter were analyzed. They observed the significant difference in swelling capacity (0.62-1.25g/g) and water absorption capacity (0.22- 0.64ml/g) was seen among the elephant foot yam starches. In the same way, significant difference in swelling capacity (0.45-0.83g/g) and oil absorption capacity (1.06-1.40ml/g) was noticed among the cush-cush yam starches. Elephant foot yam starches exhibited no significant difference in moisture content (9.99-12.13%) and dry matter

(88.46-89.99%). A similar trend was observed among the cush-cush yam starches in moisture content (14.66-17.50%) and dry matter (82.33-86.12%). Hence the starches isolated from tubers by different methods had varied functional and same chemical properties.

Lenka *et al.*, (2012) studied the tropical roots and tuber crops are considered as the third important crops after cereals and grain legume. They contribute 6% of the average daily calorific intake of human beings. The tropical roots and tuber crops (cassava, sweet potato, yams and aroids) are of utmost importance for the world food security. The popular tuber crops include sweet potato (*Ipomoea batatas*), cassava (*Manihot esculenta*), taro (*Colocasia esculenta*), yam (*Dioscorea sp.*), elephant foot yam (*Amorphophallus paeoniifolius*), yam bean (*Pachyrrhizus erosus*), arrowroot (*Maranta arundinaceae*), etc constitute cheap source of food and energy particularly suitable for the poor section of human population and capable enough to withstand biotic and abiotic stresses.

Babajide and Olowe (2013) studied the chemical, functional and sensory properties of water yam – cassava flour and its paste. They studied the Elubo flour is usually produced from traditionally steeped and dried yam (*Dioscorea rotundata*) slices/tubers while lafun flour is a fermented cassava product. During the off season of yam, the elubo retailers tend to mix water yam elubo (*Dioscorea alata*) with lafun to obtain a seemingly yam flour. Water yam flour elubo replacement substitute with cassava flour lafun were evaluated in terms of the chemical, functional properties of the flour and sensory attributes of its cooked thick paste amala. The water yam and cassava flours were blended in the ratios of 100:0, 90:10, 80:20, 70:30, 60:40, 50:50 respectively and 100% yam flour elubo as the control. Bulk density (0.55-0.67g/ml) and water absorption index (61.67-84.21%) increased with increase in amount of lafun in water yam flour, thus improving the reconstitution ability.

2.2 Extrusion cooking technology

Fellows (1998) studied the extrusion in food processing technology its principle and practice. Extrusion cooking is predominantly a thermochemical processing operation that combines several unit operations including mixing, kneading, shearing, conveying, heating, cooling, forming and partial drying or puffing depending on the material and equipment used. Some of these processes take place depending upon desired product. For example in pasta, shaping and forming is the main objective, in corn curls expansion and development of porous structure is important during extrusion processing, food materials are generally subjected to a combination of high temperature, high pressure and high shear. This can lead to a variety of reactions with corresponding changes in the functional properties of the

extruded material. In the extrusion process, there are generally two main energy inputs to the system. Firstly there is the energy transferred from the rotation of the screws and secondly the energy transferred from the heaters through the barrel walls. The thermal energy was generated by viscous dissipation and transferred through the barrel wall results in an increase in the temperature of the material being extruded. As a result of this, there may be phase changes, such as melting of solid material, and the evaporation of moisture.

Riaz, (2000) studied the extruders in food applications. The extrusion is popular because of its high flexibility. Same extruder can be used to manufacture different products using either dry or moist feed. In addition, on-line adjustments can be made to get varied product characteristics. Extrusion can be performed at low moisture hence less redrying and better energy efficiency. It is low cost equipment having high productivity rate. It is a continuous process with negligible effluent. Extrusion is high temperature short time process where food is exposed to temperatures up to 200°C for 1 to 10 seconds.

Eastman *et al.*, (2001) gives the use of extrusion to create breakfast cereal products. Extrusion can be defined as the process of forcing a pumpable material through a restricted opening. It involves compressing and working a material to form a semisolid mass under a variety of controlled conditions and then forcing it, at a predetermined rate to pass through a hole.

Guy, (2004) studied the extrusion technology for food and snack products. Extrusion cooking technologies for foods and feeds grew out of process developed by the Adams Company in the 1940s to manufacture snack foods from maize grits. They are derived from the earlier extrusion technologies used to form and extrude sausage meats and pasta. These process involving conveying, mixing and compressing of moist materials to form dough's that could be extruded as simple rod or in the case of pasta, as well-defined shapes. The temperature during the extrusion cooking is very high therefore any water present in superheated state within the dough but remains in liquid state. The high temperature also causes changes in the structure and form natural biopolymers, such as starch and soy globulins. The screw confined within a barrel that convey the dough towards small openings at the end of the barrel, the dough is compressed and heated to high temperature, while subjected to high pressures, before being extruded through the dies into the atmosphere.

Chakraborty *et al.*, (2009) studied the extrusion a novel technology for manufacture of nutritious snack foods. Extrusion cooking applications in food industry today cover a wide range of food products based on starches, cereals, proteins and sugars. Extrusion is a multivariable unit operation i.e. mixing, shearing, cooking, puffing and drying in one energy

efficient rapid continuous process. Extrusion cooking is high temperature short time process (HTST) process which reduces the microbial count and inactivates the enzymes. The products are self preserved as they have negligible water activity (0.1-0.4), which reduces microbial contamination and inactivation of enzymes (Bordoloi and Gangli, 2014). The extrudate can be very nutritious bereft of anti-nutritional factors and increased nutrient availability. It has become important technique in an increasing variety of food processes. Extrusion cooking is being increasingly used to manufacture a diverse range of food products including snack foods and slimming products. It is a popular means of preparing a snacks foods and ready-to-eat breakfast cereals using starch-based raw materials.

Muthukumarappan and Karunanithy (2012) studied the extrusion process design. Extrusion is thermomechanical process where shaping of a plastic or dough like material is obtained by forcing it through die. It has several advantages of extrusion process are versatility, energy efficiency, low cost, no effluent, process scale up, continuous high-throughput processing, ability to handle ingredients with a range of moisture contents from relatively dry to very wet materials, high product quality and control of the thermal changes which occur in the material. There are two types of extruder a) Single screw extruder have a main advantages over twin screw extruder are they are mechanically very simple and the cost is half the price of similar sized twin screw extruder. b) Twin screw extruder comprises two screws rotating either in the same direction (co-rotating) or in the opposite direction (counter-rotating).

2.2.1 Twin screw extrusion cooking

Lawal and Kalyon (1995) studied the mechanism of mixing in single and co rotating twin screw extruder. The twin screw extruders, which can involve co rotating and counter rotating screws, are generally built as molecular mixers. The fully intermeshing co rotating twin screw extruder which provides the advantage of being self wiping. The screw elements include the fully flighted screw sections and kneading discs. Fully flighted screw sections are used in melting. Melt conveying and pressurization for distributive mixing where the componanats of a formulation are interspersed in each other without altering physical properties.

Andersen (2012) studied the co-rotating fully intermeshing twin-screw compounding, advancements for improved performance and productivity. The co-rotating fully intermeshing twin-screw extruder is the primary production unit for compounding of polymer based materials. It also has had a long term presence in processing material in the chemical and

food industry and more recently in pharmaceuticals. It has not experienced a decline in new developments as might be expected, but rather a significant number of advancements continue to evolve. These are the implementation of high torque (power) designs, the use of increased rpm in conjunction with high torque for improved operating flexibility and productivity, and finally a technology breakthrough for feeding difficult to handle low bulk density materials.

2.3 Raw material used for extrusion cooking

Guy, (2001) studied the extrusion cooking of starch base material. The most used raw materials in the extrusion process are starch and protein based materials. This technique has been widely used with raw materials such as corn, wheat, rice and soybean. Natural biopolymers of raw materials such as cereals or tuber flours are rich in starch, or oilseed legumes and other protein rich sources. Most commonly used materials are wheat and corn flours, but many other materials are also used such as rice flour, potato, rye, barley, oats, sorghum, cassava, tapioca, buckwheat and pea flour. The protein rich materials such as pressed oilseed cake from soya, sunflower, rape, field bean, fava beans or separated proteins from cereals such as wheat (guten). The structure of the extruded products may be formed from starch or protein polymers. Most products, such as breakfast cereals, snacks and biscuits are formed from starch, while protein is used to produce products that have meat-like characteristics and that are used either as full or partial replacements for meat in ready meals, dried foods and many pet food products.

Moscicki, (2011) studied the extrusion cooking techniques and its applications. Typical raw materials used in the popular extruded products, each of which offers a wide variety of functions: structure-forming, facilitating physical transformation during the extrusion-cooking, affecting the viscosity of the material and its plasticization, facilitating homogeneity of the dough ingredients, accelerating starch melting and gelatinization and improving the taste and color of products.

Steel *et al.*, (2012) studied the thermoplastic extrusion in food processing. The main characteristics of the raw material for extrusion cooking are type of material, moisture content, physical state, chemical composition (quantity and type of starch, proteins, fats and sugars) and pH of the material. Most of raw materials used in food extrusion are solid.

Oke *et al.*, (2013) studied the expansion ratio of extruded water yam (*Dioscorea alata*) starches using a single screw extruder. In this study water yam was used for extrusion cooking. This was accomplished by varying the feed moisture content (FMC) and extruder

parameters which include barrel temperature (BT), screw speed (SS) and determine their effects on resulting expansion ratio using response surface methodology. The expansion ratios of all the extrudates considered in this study ranged from 1.05 to 1.93. It was observed that changing the feed moisture content, barrel temperature and screw speed significantly affected the expansion ratio of all the extrudates. Increasing the feed moisture content (18 to 28% db) and screw speed (80 to 180 rpm) resulted in a substantial decrease in expansion ratio of all the extrudates. The screw speed and feed moisture content were found to be the major process variables showing significant linear, quadratic and interaction influences on the expansion ratio. Table 2.4 shows the sources of raw materials used by the different researches for extrusion cooking.

Singh *et al.*, (2014a) prepared extruded from Bengal Gram Broken and Maize Flour Blends and evaluate its extrusion characteristics. The properties of product were evaluated on the basis of mass flow rate (MFR), specific length of extrudates (SL), sectional expansion index (SEI), longitudinal expansion index (LEI) and water absorption index (WAI). Protein content of extrudates was also measured to analyze and evaluate the nutritional value of product. The best quality extrudates were obtained at 80°C barrel temperature, 10% moisture content of feed, 20% blending ratio followed by 10% moisture content, 85°C barrel temperature and 25% blending ratio. Also this processing approach enables the value addition of Bengal gram broken and maize flour for preparation of extruded snack food. Table 2.4 shows the raw material used by different researchers for extrusion cooking.

Table 2.4: Raw material used by different researchers for extrusion cooking.

Sr. No.	Raw material	Researcher (s)
1	Cassava, maize and wheat flour	Fayose <i>et al.</i> , 2015
2	Wheat, mungbean and groundnut	Pathania <i>et al.</i> , 2013
3	Water yam starches	Oke <i>et al.</i> , 2013
4	Rice-Sweet potato and rice-yam	Hazarika <i>et al.</i> , 2013
5	Broken rice flour, pineapple waste pulp powder and red gram powder	Kothakota <i>et al.</i> , 2013a
6	African yam bean and cassava flour	Omeire, 2012
7	Pearl millet	Singh and Devi, 2011
8	Tef, corn and soy protein isolated blends	Forsido and Ramaswamy, 2011
9	Corn, millet and soybean	Semasaka <i>et al.</i> , 2010
10	Carrot pomace, rice flour and pulse powder	Kumar <i>et al.</i> , 2010
11	Arrowroot starch	Jyoti <i>et al.</i> , 2009
12	Barnyard millet and red gram	Chakraborty, 2008
13	Defatted soy flour and rice	Garg, 2005

14	Corn grits	Arhaliass <i>et al.</i> , 2003
15	Lentil based snacks	Banerjee <i>et al.</i> , 2003
16	Rice and moong flour	Jha and Prasad, 2003
17	Faba bean and rice	Singh, 2003
18	Soy and maize	Singh <i>et al.</i> , 2003
19	Lentil starches	Gonzalez and Perez, 2002
20	Defatted chick pea, corn and bovine lung flour	Cardosa <i>et al.</i> , 2001
21	Full fat soy flour (FFSF) and cereal or pulse flour	Deshpande <i>et al.</i> , 2001
22	Broken rice and corn grits	Boonyasirikool and Charunch, 2000
23	Mustered oil and rice grits	Kaur <i>et al.</i> , 2000
24	Faba beans	Rajawat <i>et al.</i> , 2000
25	Yam flour	Sebio and Chang, 2000
26	Potato and wheat flour	Bhattacharya <i>et al.</i> , 1999
27	Rice flour and amaranth	Llo <i>et al.</i> , 1999
28	Soy flour and maize	Adesina <i>et al.</i> , 1998
29	Garbanzo bean, lentil, whole peas and split peas	Tang <i>et al.</i> , 1998
30	Soybean-sweet potato mixture	Iwe <i>et al.</i> , 1998
31	Rice and chick pea	Bhattacharjee <i>et al.</i> , 1997
32	Wheat starch, whole wheat meal and oat flour	Smith and Singh, 1996
33	Maize grits	Llo <i>et al.</i> , 1996
34	High moisture fish and soy protein	Maryse <i>et al.</i> , 1996
35	Wheat/ rice semolina and potato grits	Singh <i>et al.</i> , 1996
36	Soyabean meal	Ling and Chou, 1995
37	Barley and rice flour, wheat flour	Berguland <i>et al.</i> , 1994
38	Soyabean and sorghum flour	Patil <i>et al.</i> , 1992
39	Wheat flour, roasted Bengal gram, green gram, ground nut, jowar, skimmed milk powder and jiggery	Tabitha <i>et al.</i> , 1992
40	Rice and soyabean residues	Wu and Chiang, 1991
41	Maize	Hazel and Johnson, 1989
42	Full fat soy flour	Hovarth <i>et al.</i> , 1989
43	Corn starch	Chinnaswamy and Hanna, 1988
44	Sorghum varieties	Fapojuwo <i>et al.</i> , 1987

2.4 Flour formulation

Chauhan and Bains (1985) summarized the findings that increased proportion of defatted soy flour blended with rice flour notably decreased the expansion ratio and increased the product density. The product exhibited maximum expansion ratio and minimum density of 2.8, 2.7 and 0.35, 0.33 respectively. However, addition of 15% defatted soy flour improved the textural properties slightly, as reflected by brittleness, irrespective of rice variety. Extrusion cooking exhibited an increase of 2 to 3 fold in water absorption index and 4 to 5 fold increase in water solubility index. The addition of 15 percent soy flour had no effect on the water absorption capacity of the product but there was slight decrease with 30 per cent

soy flour. The extruded rice snack with 15% defatted soy flour was found to be highly acceptable.

Das *et al.*, (1988) studied that an extrusion cooked corn-soy milk snack had the minimum wet density of 1127 kg/m³ with 6.35 mm die and the maximum expansion ratio of 1.105 with 4.75 mm die. Although the rate of production was highest with 8 mm die, the minimum specific power consumption of 57.2 KJ/kg was obtained at 70 rpm with 4.75 mm die.

Patil *et al.*, (1990) for extrusion of soy rice blends in proportion of 30:70. It was observed that extrusion at lower level of moisture (12%, wb) is most suitable. The highly puffed product having bulk density of 266.23 kg/m³, water absorption index of 4.09 was obtained at this level of feed moisture. The moisture content of the final product was 6.0 per cent (wb) avoiding need for further drying.

Adesina *et al.* (1998) formulated blend of maize-soy based ready-to-eat extruded snack foods. They conducted that maize alone gave the highest expansion (4.63) and contributed to enhanced expansion and colour of different blends. On the other hand, soy alone gave the least expansion (1.25) upon extrusion, but contributed to improved textural characteristics of the extrudates while 75:25 maize: soy blend extruded at 150⁰C exhibited optimum quality characteristics. Addition of 10 per cent sugar reduced expansion and hardness of the product while addition of 2 per cent chilli reduced only its hardness. However, both were acceptable. Inclusion of soy improved the protein content of the blend.

Zasytkin and Lee (1998) reported their findings that expansion ratio of wheat flour and soy flour extrudates increased with lowering the moisture content. Unexpectedly, the expansion ratio decreased with lower the moisture content for the composite extrudates. Optimal extrudate properties at 16 per cent (wb) moisture content corresponded to 80, 90 and 100 per cent (db) wheat flour and 20, 10 and 0 per cent soy flour respectively. At 17 and 18 per cent moisture content, optimal properties were found for products containing 80 or 90 per cent wheat flour and 20 or 10 per cent soy flour respectively.

Konstance *et al.*, (1998) developed nutrient-based corn and soy extruded product using twin screw extrusion to provide 20% protein, 12% fat, 68% carbohydrate and 8% moisture. High protein soy products namely full fat flakes, protein isolate and/or concentrate were formulated with corn meal and soybean oil to provide high protein and fat. The blends were extruded to provide pre-cooked foods that could be reconstituted at 40⁰C to a porridge or gruel, eliminating prolonged cooking or degradation of heat labile nutrients at extrusion temperatures from 100 to 130⁰C and feed moistures 8.5 to 18%. The result indicated that the

extrusion of lower valued concentrates at 100 to 115⁰C with moisture from 12 to 18% produced a precooked mix that was high in nutrients and contained the most available lysine.

Patil *et al.*, (2000) reported that the characteristics of full fat soy flour blended with wheat flour in proportion of 10, 20 and 30 per cent at three feed moisture levels of 15, 20 and 25 per cent (wb) and three barrel temperatures of 80, 90 and 100⁰C. Analysis of various quality indices of extrudates with process variables indicated optimum condition of 10 per cent blending of full fat soy flour (FFSF), 25 per cent moisture content and 90⁰C barrel temperature. The second set of experiment conducted on defatted soy flour, showed optimum condition of 10 per cent blend, 15 per cent moisture content and 90⁰C barrel temperature. The best water absorption index of about 55 per cent was achieved at 15 per cent moisture content and 90⁰C temperature.

Chakraborty and Banerjee (2009) employed response surface methodology to study effect of feed moisture and metering zone temperature on physical properties of green gram extrudates. Temperatures and moisture had significant effect on expansion ratio, which decreased with increasing moisture content. Feed moisture and die head temperature had negative effect on water holding capacity. With increase in barrel screw speed, viscosity of rice-green gram dough decreased resulting lesser power consumption and developed pressure at die head.

Kumar *et al.*, (2010) formulated blends of carrot pomace, rice flour and pulse powder for twin screw extrusion cooking. Rice flour was added in different proportions (10 - 30%) to dehydrated carrot pomace and pulse powder (CPPP) mixture having equal ratio. The formulation was extruded at different moisture content (17 - 21%), screw speed (270 - 310 rpm) and die temperature (110 - 130⁰C). The lateral expansion, bulk density, water absorption index, water solubility index, hardness and sensory characteristics were measured as responses. The results indicated that CPPP proportion and moisture content significantly influenced lateral expansion; temperature for water absorption index; screw speed and temperature for hardness and screw speed for sensory score. The compromised optimum condition obtained by numerical integration for development of extrudates were: CPPP mixture of 16.5% in rice flour, moisture content 19.23%, screw speed 310 rpm and die temperature 110⁰C. Sensory evaluation revealed that carrot pomace could be incorporated into ready-to-eat expanded products up to the level of 8.25%.

Carine *et al.*, (2010) studied the optimization of extrusion on blends flour composed of corn, millet and soybean. Formulation of corn 44%, millet 36% and soybean 20% made with an objective to optimize four nutrients like protein 17%, fat 3%, dietary fiber 5% and

iron 3.5µg. The response variables were analysed like bulk density, water absorption index, water solubility index, pasting properties, swelling power and colour of the extrudate. He reported that, product cooked with conditions moisture (25-30%), temperature 80, 110, 140 and 170°C, screw speed 130 rpm and feed rate 37g/min were best.

Semasaka *et al.*, (2010a) made formulations of blends of 44% corn flour, 36% millet flour and 20% soybean flour were performed. The blends were extruded in Twin screw extruder. The explanatory variables used were 4 temperature (for the feeding, mixing, cooking and die zones), Rolling speed, feeding speed and moisture content of the samples. The response variables were bulk density, WAI, WSI, pasting properties, thermal analysis, swelling power and the color of the extrudates. The better factors and levels showed that the temperature 80, 110, 140 and 170°C, rolling speed of 110 rpm, feeding speed of 37 g/min and moisture content varies from 25-30% are the best for the extrusion of that formulation.

Omeire (2012) formulated extruded blends of African yam bean (*Sphenostylis stenocarpa*) and cassava flour. Extrusion runs were conducted using different ratios of feed blends in single screw extruder (0.54:99.46; 20:80; 50:50; 80:20; 99.46:0.54) cassava flour/AYB flour. The raw and extruded products were subjected to amino acid analysis. All the amino acids in the raw samples appeared in the extruded products and were proportionally increased as the percentage of AYB increased. The results of the amino acid profile of cassava flour were generally lower except for arginine and glutamic acid, the highest level of loss for AYB was obtained in lysine (62.4%), followed by glycine (47.43%) and aspartic acid (44.96%). Leucine had the lowest percentage loss of 14.14%. The results indicated that extrusion cooking altered the amino acid profile of the extrudates and that blending increased the nutritional value of the products.

James and Nwabueze (2013) formulated blend of african breadfruit-soybean-corn. The raw flour blend was extruded in a single screw extruder at 21% moisture content, 140°C barrel temperature, 140 rpm screw speed fitted with 2mm die nozzle diameter. Food extrusion significantly ($p < 0.05$) reduced the moisture and crude protein from 21.00 to 9.70% and from 30.80 to 24.50% respectively. Extrusion cooking did not significantly ($p > 0.05$) affect the fat, crude fibre and energy values of the extrudates. While ash and carbohydrate contents were significantly ($p < 0.05$) increased from 2.85 to 5.15% and from 48.00 to 54.10% respectively upon extrusion.

Pathania *et al.*, (2013b) formulated blend of wheat, mungbean and groundnut. The effects of feed moisture, barrel temperature and screw speed on product responses viz. specific mechanical energy (SME), expansion ratio (ER), density (BD), water absorption

index (WAI) and water solubility index (WSI) was studied using response surface methodology. The blend was extruded at different moisture content (12.6 -19.4%), screw speed (349 - 601 rpm) and barrel temperature (116 - 184°C). The regression models for SME, expansion ratio, bulk density, WAI and WSI were highly significant. SME has been found to decrease with increase of moisture and temperature and increased with increase in screw speed. Expansion ratio and density were significantly affected by feed moisture and temperature. WAI and WSI were found to decrease significantly with increase in moisture content and increased significantly with increase in Screw speed and temperature. The optimum values for moisture content, screw speed and temperature were 14.08%, 521 rpm and 140°C respectively. The desirability was found to be 0.835 for this model.

Hazarika *et al.*, (2013) formulated the blends for rice (*Oryza sativa*)—Sweet potato (*Ipomoea batatas*) and rice-yam (*Dioscorea alata*) based RTE products. Taking rice flour as the base ingredient, two locally available tuberous root vegetables, greater yam (*Dioscorea alata*) and sweet potato (*Ipomoea ba-tatas*) were used in a single screw extruder. During extrusion cooking, the screw speeds ranged from 132 to 468 rpm and the barrel temperatures ranged from 103°C to 137°C. The extrudates were then analyzed for various physical and physicochemical properties. Using screw speed, barrel temperature and feed composition as the three independent variables, the three responses taken were bulk density, expansion index and breaking strength. The products were analyzed for their physical, proximate, sensory and antioxidant properties. Rice flour incorporated with sweet potato was judged the best on sensory evaluation. The study has shown that both sweet potato and greater yam tubers can be commercially exploited for the development of ready-to-eat (RTE) products.

Kothakota *et al.*, (2013b) formulated the blends of broken rice flour was added in proportions (75%) to equal amount of dehydrated pineapple waste pulp powder and red gram powder (12.5%) were extruded in a twin-screw extruder. The formulation was extruded at different moisture content (17-21%), screw speed (260-340 rpm) and die temperature (120-140°C). The lateral expansion, bulk density, water absorption index, water solubility index, hardness and sensory characteristics were measured as responses. In the experiments, increase in barrel temperature resulted in extrudate with higher expansion, higher hardness, lower bulk density, lower WSI and higher WAI. Increasing in screw speed resulted in higher expansion, lower bulk density, higher overall acceptability and lower hardness; whereas, increasing level of moisture resulted in lower hardness, lower expansion and minimum bulk density and higher overall acceptability. In the experiment, optimization studies resulted in 132.27°C of barrel temperature, 315 rpm of screw speed and 18.48% of feed moisture.

2.5 Effect of extrusion parameters on functional and nutritional properties

Patil *et al.* (1992) reported that the amylase content starch definitely helps in improving the expansion of extruded product without affecting the specific mechanical energy requirement for the extrusion process.

Singh *et al.*, (2007) reviewed the nutritional aspects of food extrusion. They concluded that effects of extrusion cooking on nutritional quality are ambiguous. Beneficial effects include destruction of antinutritional factors, gelatinization of starch, increased soluble dietary fibre and reduction of lipid oxidation. On the other hand, Maillard reactions between protein and sugars reduce the nutritional value of the protein, depending on the raw material types, their composition and process conditions. Heat-labile vitamins may be lost to varying extents. Changes in proteins and amino acid profile, carbohydrates, dietary fibre, vitamins, mineral content and some non-nutrient healthful components of food may be either beneficial or deleterious. Mild extrusion conditions (high moisture content, low residence time, low temperature) improve the nutritional quality, while high extrusion temperatures (200°C), low moisture contents (<15%) and/or improper formulation (e.g. presence of high-reactive sugars) can impair nutritional quality adversely. To obtain a nutritionally balanced extruded product, careful control of process parameters is essential.

Kasprzak and Rzedzicki (2008) investigated the possibility of applying seeds of everlasting pea (*Lathyrus sativus*) in the extrusion-cooking technology. Extrudates were used to analyse the effect of an addition of everlasting pea wholegrain meal on the content of ash, fat, protein, and dietary fibre. The share of everlasting pea wholegrain meal in the raw material mixture varied from 3 to 21%. Corn semolina was used as the structure-forming component. The process of extrusion was conducted using a single screw extrusion-cooker (L:D = 12:1, D = 45 mm) at raw material moisture content of 12-16% and at barrel temperature distribution profiles from 115/135/120 to 155/175/120°C. As a result of the process of extrusion, a reduction was observed in the content of fat, protein, raw fibre, neutral-detergent fibre, acid-detergent fibre, hemicellulose, cellulose, total dietary fibre and insoluble dietary fibre. At the same time an increase was recorded in the content of soluble dietary fibre and lignin.

Altan *et al.*, (2008a) studied twin screw extrusion of barley-grape pomace blends: Extrudate characteristics and determination of optimum processing condition. Grape pomace was mixed thoroughly with barley flour to the ratio of 0, 2, 6, 10, and 12.73 percent (db). Blends were extruded in a 30 mm APV co-rotating twin screw extruder. Response surface

methodology using central composite design was to evaluate the effects of independent variables, die temperature (140-160°C), screw speed (150-200 rpm) and pomace level (2-10 percent) on product responses functional properties like expansion, bulk density, texture and colour. Sensory evaluation was carried out for appearance, taste, texture off-odor and overall acceptability. He reported that, blends of 2 percent grape pomace extruded at 160°C, 200 rpm and 10 percent grape pomace extruded at 160°C, 150 rpm had higher preference levels for parameters of appearance, taste, texture off-odor and overall acceptability.

Altan *et al.*, (2008b) studied evaluation of snack food from barley-tomato pomace blends by extrusion processing. Blends were prepared by mixing barley flour and tomato pomace in the ratios 100:0, 98:2, 94:6, 90:10, 87.27:12.73 on dry- to- dry weight basis. Response surface methodology using central composite design was to evaluate the effects of independent variables, die temperature (140-160°C), screw speed (150-200 rpm) and pomace level (2-10 percent) on product responses functional properties like expansion, bulk density, texture and colour. Sensory evaluation was carried out for appearance, taste, texture off-odor and overall acceptability. He reported that, extrudate with 2 percent and 10 percent tomato pomace extruded at 160°C, 200 rpm had higher preference levels for parameters of appearance, taste, texture off-odor and overall acceptability.

Altan *et al.*, (2008c) studied the twin screw extrusion of barley-grape pomace blends. He reported the extrudate characteristics and determination of optimum processing conditions. Independent variables are die temperature (140-160°C), screw speed (150-200 rpm) and pomace level (2-10% db) on product response (expansion, bulk density, texture and colour), sensory analysis was carried out for selected extrudates for appearance (colour, porosity), taste (bran flavor, bitterness and sweetness), off-odor, texture (hardness, crispiness and brittleness) and overall acceptability. Multiple regression equations fitted for these properties. The product responses were most affected by change in temperature, pomace level and lesser extent by screw speed. Blends of 2% grape pomace extruded at 160°C, 200 rpm and 10% grape pomace extruded at 160°C, 150 rpm had higher preferences levels for parameters of appearances, taste, texture and overall acceptability. Increasing in extrusion temperature with decreasing expansion ratio, decreasing bulk density and decreasing hardness of extrudates.

Jyothi *et al.*, (2009) studied the physical and functional properties of arrowroot starch extrudates. Different levels of feed moisture (12%, 14%, and 16%) and extrusion temperatures (140, 150, 160, 170, 180, and 190 °C) were used for extrusion. The different physical properties like bulk density, true density, porosity, expansion ratio, water absorption

index, water solubility index, oil absorption index, pasting, rheological, and textural properties of extrudates were determined. The expansion ratio of the extrudates ranges from 3.22 to 6.09. The water absorption index (6.52 to 8.85 g gel/g dry sample), water solubility index (15.92% to 41.31%), and oil absorption index (0.50 to 1.70 g/g) were higher for the extrudates in comparison to native starch (1.81 g gel/g dry sample, 1.16% and 0.60 g/g, respectively).

Garg and Singh (2010) studied the optimization of extrusion conditions for defatted soy-rice blend extrudates. processing parameters of feed including moisture content of feed (12, 15, 18, 21 and 24%), soy flour-rice blend ratio (10:90, 14:86, 18:82, 22:78 and 26:74) operational parameters of extruder like barrel temperature (110, 120, 130 and 140°C), die temperature (160, 170, 180, 190 and 200°C) and screw speed (100, 110, 120, 130 and 140 rpm) were optimized for physical and textural properties of soy-rice blend extrudates. The minimum value of longitudinal expansion index lied near 185°C die temperature at about 120 rpm. The minimum value of bulk density observed in between 18:82 blend ratio and 115°C barrel temperature.

Semasaka *et al.*, (2010) studied the effect of flour formulation (corn, millet and soybean), temperature and screw speed on functional properties of extrudates. Bulk density of extrudates increases with increase in temperature of extrusion. Water solubility index was increased with increase in temperature. The result shows that the bulk density of extruded product 0.8974-1.0782 g/cc, WAI ranges from 3.63-6.04 g/g, WSI varies from 9.1-16.95% and swelling power varied from 5.42-13.79.

Giannini *et al.*, (2010) studied the quality properties of corn-based extrudates enriched with dietary fibers. Simple power models were developed to predict porosity and compression stress as functions of process conditions and material composition. The extrusion conditions regulated were the feed rate (0.5-2.0 g/s) and the extrusion temperature (150-230°C), at a speed of screw rotation of 200 rpm. The feed material moisture content was regulated from 13 to 19% (wet basis) and the fiber to corn ratio was ranged from 10 to 30% for both types of extrudates. Porosity of extrudates was found to decrease with temperature, feed moisture content and fiber to corn ratio and to increase with feed rate for both the examined fibers. The same tendency was also found for the expansion ratio of extrudates, while the stress of compression revealed the opposite behavior. The true density of apple fiber/corn extrudates ranged at 1550 ± 387 (kg/m³), while that of oat fiber/corn ranged at 1450 ± 207 (kg/m³).

Thakur and Tomar (2010) studied the effect of inclusion of soybean and potato on nutritional and sensory quality of rice based extrudates. blends of rice, soybean and potato in ratio of 100:0:0, 80:10:10 and 70:10:20 were prepared and extrudates were made by Brabender single screw extruder at three moisture levels of feed (12, 15 and 18%) at three barrel temperature (180, 200 and 220°C) at constant screw speed (100 rpm). The good quality product could be made at 200°C barrel temperature with 15% feed moisture had superior quality. Protein content varied from 6.85 to 10.66 %, ash content of extrudates ranged from 0.84 to 1.68 %, carbohydrates ranged from 68.10 to 74.69% and moisture content ranged from 8.35 to 12.07 %.

Oke *et al.*, (2010) studied the effect of extrusion variables on extrudates properties of water yam flours-a response surface analysis. The effect of extrusion and process variables: Feed Moisture Content (FMC), Screw Speed (SS) and Barrel Temperature (BT) on the extruder torque, residence time, mass flow rate, specific mechanical energy and expansion ratio for the entire varieties were determined and predictive models were also developed using response surface methodology. It was generally observed that changing the feed moisture content, barrel temperature and screw speed significantly ($p \leq 0.05$) affected expansion ratio, torque, mass flow rate, residence time and specific mechanical energy of all the extrudates. Increasing the feed moisture content (18-28% db) and screw speed (80-180rpm) resulted in a substantial decrease in expansion ratio (46.6%), residence time (27.5%), and specific mechanical energy (83.6%). Regression analysis indicated that screw speed and feed moisture content were the major process variables showing significant ($p \leq 0.05$) linear, quadratic and interaction influences on mass flow rate, expansion ratio and specific mechanical energy.

Forsido *et al.*, (2011) studied the protein rich extruded products from tef, corn and soy protein isolate blends. They gave the procedures of determination of color value, rehydration ratio and water solubility index, expansion ratio, hardness and bulk density of extruded products. They observed in the Changing the levels of ingredients significantly affected color (L^* , a^* and b^*) rehydration ratio and water solubility index. Expansion ratio ranges from 1.69-1.95, bulk density ranges from 0.35-0.56 g/ml, water solubility index ranges from 0.35-1.14, rehydration ratio ranges from 114.91-496.18 % and hardness is ranges from 12.43-92.64 N.

Lui *et al.*, (2011) studied the preparation, physicochemical and textural properties of texturizer rice (TR) produce by improved extrusion cooking technology. The feed moisture content (26.6-33.4%), screw speed (20.1-32.6rpm) and shearing compression metering zone

temperature (SCMT, 69.8-120.0°C) on the physicochemical, texture and nutritional characteristics of TR. When the bran addition 4%, feed moisture content was 30%, screw speed 26.6 rpm, SCMT was 95°C prepared TR contained 16.61±0.02% of total dietary fibers, 9.40±0.04% of protein, 3.68±0.03% of fat. The results was low screw speed led to increase of TR bulk density value, increase in temperature caused decrease in bulk density from 0.66-0.32 g/cc, decrease in WAI from 6.2-3.3 g/g, increase WSI from 6.8-22.6 % and increased hardness from 335-378 g of extrudates. Increased screw speed increased the WAI, increased WSI and increased hardness of TR extrudates.

Balasubramanian *et al.*, (2012) studied the rheological and nutritional properties of legumes incorporated corn extrudates. Rheological and nutritional properties of corn based extrudates incorporated with selected dehulled legumes (black gram, green gram, lentil and peas) made using low cost collet extruder at 5%, 10% and 15% levels were studied. There was a decreasing trend of all viscosity properties and degree of gelatinization with increase in legumes incorporation level. With increase in legumes incorporation, protein content showed an increasing trend and fat, fiber, ash content and sensory score remain almost same. Thus, dehulled legumes (up to 15%) incorporated corn extrudates have showed a promising trend for the production of low cost expanded snacks and instant flour.

Manjula and Visvanathan (2012) studied the process optimisation of extruded breakfast cereal from rice mill broken-finger millet-maize flour blends. The effect of extrusion on the physical, functional and textural properties of broken rice extrudates blended with finger millet and maize flours of various formulations were studied. The density of blends ranged from 0.11 to 0.44 g/cm³, expansion ratio (1.54-2.46), true density (78.91-477.84 kg/m³), porosity (28.13-37.95%), WAI (5.0-8.05 g/g), WSI (0.2-8.7%) and hardness (1.35-10.09 N). It was observed that the increase in feed moisture content resulted in extrudates with a lower expansion ratio and WAI, higher density, WSI and hardness. Among the various combinations investigated the blend with broken rice (30), finger millet (60) and maize (10), 16 per cent moisture addition, 110°C barrel temperature and 290 rpm screw speed yielded good sensory results. The results obtained from the experiments were significantly different at ($P \leq 0.01$) of all combinations.

Bisharat *et al.*, (2013) studied that effect of extrusion conditions on the structural properties of corn extrudates enriched with dehydrated vegetables. The extrudates obtained using a twin-screw extruder, operated at different conditions, including screw speed (150 rpm, 200 rpm and 250 rpm) and extrusion temperature (140 °C, 160 °C, 180 °C). The moisture content of the raw mixture was regulated in three levels (14%, 16.5%, 19%),

whereas the concentration of the added ingredient was adjusted to 4%, 7% and 10% for broccoli and to 4%, 6% and 8% for olive paste. Structural properties and rehydration were investigated with regard to process conditions and material characteristics. They concluded the products with 14% moisture content and 4% material concentration extruded at the highest screw speeds (250 rpm) presented the highest degree of expansion.

Oke *et al.*, (2013) studied the expansion ratio of extruded water yam (*Dioscorea alata*) starches using a single screw extruder. During extrusion cooking varying the feed moisture content (FMC) and extruder parameters which include barrel temperature (BT), screw speed (SS) and determine their effects on resulting expansion ratio using response surface methodology. A single screw extruder (DCE 330, NJ) was used in evaluating the extrudate's physical property. The expansion ratios of all the extrudates considered in this study ranged from 1.05 to 1.93. It was observed that changing the feed moisture content, barrel temperature and screw speed significantly ($P < 0.05$) affected the expansion ratio of all the extrudates. Increasing the feed moisture content (18 to 28% db) and screw speed (80 to 180 rpm) resulted in a substantial decrease in expansion ratio of all the extrudates. The screw speed and feed moisture content were found to be the major process variables showing significant ($P \leq 0.05$) linear, quadratic and interaction influences on the expansion ratio.

Kothakota *et al.*, (2013c) study on evaluation and characterization of extruded product by using various by-products. Broken rice flour was added in proportions (75%) to equal amount of dehydrated pineapple waste pulp powder and red gram powder (12.5%) were extruded in a twin-screw extruder. The formulation was extruded at different moisture content (17-21%), screw speed (260-340 rpm) and die temperature (120- 140°C). The lateral expansion, bulk density, water absorption index, water solubility index, hardness and sensory characteristics were measured as responses. In the experiments, increase in barrel temperature resulted in extrudate with higher expansion, higher hardness, lower bulk density, lower WSI and higher WAI. Increasing in screw speed resulted in higher expansion, lower bulk density, higher overall acceptability and lower hardness. In the experiment, optimization studies resulted in 132.27°C of barrel temperature, 315 rpm of screw speed and 18.48% of feed moisture.

Pathania *et al.*, (2013b) studied the optimization of extrusion processing conditions for preparation of an instant grain base for use in weaning foods. A blend of wheat, mungbean and groundnut was used for preparation of extrudates. The blend was extruded at different moisture content (12.6 -19.4%), screw speed (349 - 601 rpm) and barrel temperature (116 - 184°C). SME has been found to decrease with increase of moisture and temperature

and increased with increase in screw speed. Expansion ratio and density were significantly affected by feed moisture and temperature. WAI and WSI were found to decrease significantly with increase in moisture content and increased significantly with increase in screw speed and temperature. The optimum values for moisture content, screw speed and temperature were 14.08%, 521 rpm and 140°C respectively.

Nor *et al.*, (2013) studied the development of expanded snack product made from pumpkin flour-corn grits: effect of extrusion conditions and formulations on physical characteristics and microstructure. Ready-to-eat snacks were made by extruding corn grits with 5%, 10%, 15% and 20% of pumpkin flour. Snacks made from 100% corn grits were used as control products for extruded products. The effects of formulation and screw speeds of 250 rpm and 350 rpm on physical characteristics (expansion ratio, bulk density, true density and hardness) of the snacks were studied. When pumpkin flour was added the specific mechanical energy (SME) decreased by approximately 45%. Increasing the percentage of *Foods* pumpkin flour at the higher screw speed resulted in a harder texture for the extruded products.

Oluwole *et al.*, (2013) studied the physicochemical properties of extrudates from white yam and bambara nut blends. A blend of white yam grit (750 μm) and Bambara nut flour (500 μm) in a ratio of 4:1, respectively was extrusion cooked at varying screw speeds 50-70 r.p.m., feed moisture 12.5-17.5% (dry basis) and barrel temperatures 130-150°C. The extrusion variables employed included barrel temperature, screw speed, and feed moisture content, while the physicochemical properties of the extrudates investigated were the expansion ratio, bulk density, and trypsin inhibition activity. The results revealed that all the extrusion variables had significant effects ($p < 0.05$) on the product properties considered in this study. The expansion ratio values ranged 1.55-2.06, bulk density values ranged 0.76-0.94 g cm^{-3} , while trypsin inhibition activities were 1.01-8.08 mg 100 g⁻¹ sample.

Singh *et al.*, (2014c) studied the extrusion characteristic of bengal gram brokens and maize flour blends for preparation of extruded snack food. Extruded products from Bengal gram (*Cicer arietinum* L.) brokens and maize (*Zea mays* L.) flour blends were prepared on a BTPL-LAB Twin Screw Extruder. The effect of extrusion cooking parameters (mainly moisture content in blend, and barrel temperature) and blend ratio on quality of extruded products were determined. The properties of product were evaluated on the basis of mass flow rate (MFR), specific length of extrudates (SL), sectional expansion index (SEI), longitudinal expansion index (LEI) and water absorption index (WAI). Protein content of extrudates was also measured to analyze and evaluate the nutritional value of product. The

best quality extrudates were obtained at 80°C barrel temperature, 10% moisture content of feed, 20% blending ratio followed by 10% moisture content, 85°C barrel temperature and 25% blending ratio.

Peluola-Adeyemi *et al.*, (2014) studied the effect of some extrusion parameters on the nutrient composition and quality of a snack developed from cocoyam (*Xanthosoma sagittifolium*) flour. The moisture content of feed (22, 24 and 26%), screw speed (60, 70 and 80 rpm) and barrel temperature (200, 220 and 240 °C) on the functional and physical properties (density, expansion, water absorption index, water solubility index and hardness) of the extrudates. Nutritional composition of snacks also determined. Increase in barrel temperature decrease the density, water absorption index, hardness in the extrudates but to increase in expansion and water absorption index in the extrudates. The nutrient value for the extruded snacks was protein (3.76%), fiber (6.41%), carbohydrate (79.50%). Increase in barrel temperature cause decrease in the density, increase in expansion ratio, decrease in water absorption index, increase water solubility index and decreases hardness of extrudates and increase in screw speed with decrease in bulk density, increases water absorption capacity and decreases hardness of extrudates.

2.6 Sensory analysis

Laike *et al.*, (2010) studied the effect of extrusion variables including barrel temperature (110, 130 and 150°C), feed moisture content (17, 21 and 26 % wb) and screw speed (100 and 140 rpm) on the physical and sensory properties of an extruded product was investigated using two tef cultivars, red and white coloured, respectively. The study showed significant differences ($p \leq 0.05$) in hedonic rating for colour texture and overall acceptance between products as evaluated by the sensory panels. In general, extrusion variables induced significant changes in the product quality attributes evaluated.

Deshpande *et al.*, (2011) studied the physical and sensory characteristics of extruded snacks prepared from foxtail millet based composite. Blends were prepared by mixing foxtail millet flour and other flours namely rice flour, chick pea flour, amaranth seed flour and cow pea flour in ratios 70:07:05:10:08, 60:05:05:20:10 and 50:10:05:30:05. Nutritional properties of the blends were analyzed; the extrusion cooking was carried out in co-rotating twin screw extruder (Clextral BC 21, France). The temperature of the two barrel zones of extruder from feeder end were set at 90°C and 110°C and screw speed at 130 rpm and equipped with 3 mm die to extruder. The physical properties namely bulk density, piece density, expansion ratio and moisture retention were analyzed. The organoleptic qualities of extruded sample were

analyzed by panelists on a 9 point hedonic scale. They reported that, composite flour in ratios 60:05:05:20:10 could be used to produce quality extrudates and acceptable sensory properties.

Hazarika *et al.*, (2013) studied the optimization of extrusion cooking conditions and characterization of rice-sweet potato and rice-yam based RTE products. During extrusion cooking screw speed ranged from 132 to 468 rpm, and barrel temperature ranged from 103 to 137°C. Rice flour incorporated with sweet potato was judged the best on sensory evaluation. The extrudates were subjected to sensory analysis for the attributes of appearance, color, taste, mouthfeel, texture and overall acceptability by a panel of 10 semi trained panelists. Rice flour incorporated with sweet potato was judged the best on sensory evaluation.

2.7 Packaging and storage

Lasekan *et al.*, (1994) studied the maize based extruded snack which was stored at incubators maintained at 25, 30 and 40°C, storage period for 90 days in Laminated polyester (0.5 mm), aluminum (0.0035 mm) and polypropylene (2.0 mm). They resulted the Total carbonyls were found to increase in the products with increases in storage temperature. Storage of the maize snack foods at 25°C and 30°C for 30 days did not change the acceptability of the food. Higher storage temperature (40°C) reduced the sensory acceptability of the snack from 'like very much' to 'like slightly' after 30 days of storage.

Lasekan *et al.*, (1996) studied the effect of extrusion cooking conditions on the nutritional value, storage stability and sensory characteristics of a maize-based snack food. The effect of extrusion cooking on the nutritional value, storage stability and sensory characteristics of an indigenous maize-based snack food were examined. Samples were analysed for available lysine loss, protein dispersibility index (PDI), changes in total carbonyls (lipid oxidation) and sensory characteristics during storage (at 25, 30 and 40 °C). Extruded samples suffered low loss (10%) in available lysine but had an appreciable reduction in PDI. Storage at moisture contents above the monolayer region reduced greatly the total carbonyls in samples. However, total carbonyls of products were found to increase with increase in storage temperature. In addition, storage at high temperature (40°C) significantly reduced the sensory acceptance of the maize-based snack.

Rocha Guzman *et al.*, (2006) studied the functional properties of three common bean (*Phaseolus vulgaris*) cultivars stored under accelerated conditions followed by extrusion. Three common bean (*Phaseolus vulgaris*) were stored conditions for aging at 40 °C and 60% RH for 3 months in polypropylene pouches. They resulted the on storage condition of

extruded, the effect of feed moisture has not significant differences, but the effect of cultivar, temperature and storage were significant in all experimental conditions. The use of stored bean grain resulted in higher values of WAI. The standard deviation range was higher in stored beans processed at higher temperatures and it was independently of the bean cultivar used.

Saurabh *et al.*, (2013) studied the development, quality evaluation and packaging materials on the storage stability of snack food (SEV). Study was conducted on development, quality evaluation and storage stability of snack food prepared by using different proportions of multipurpose flour (wheat flour, gram flour and cowpea flour). The main objective of fortification of cowpea flour in the wheat and gram flour was to increase nutritional value of snack food. The cowpea flour was mixed in different proportion (10, 20, and 30%) and then samples were evaluated at the beginning and at interval of 15, 30, 45, 60, 75, and 90 days for chemical, sensory and microbiological analysis in order to study the storage stability of the product. It was found that storage stability of 20% cowpea packed in combination film CF sample C20 snack food had the adequate and standard amount of fat content 29.04 to 22.04, protein content 14.08 to 14.01, free fatty acid (FFA) 0.15 to 0.37 and given maximum acceptability of the product.

Oluwole *et al.*, (2013) studied the assessment of microbial changes and nutritional qualities of extruded white yam (*Dioscorea rotundata*) and bambara groundnut (*Vigna subterranean*) blends. White yam and Bambara groundnut blends which was stored at room temp. ($28\pm 2^{\circ}\text{C}$) and at refrigeration temperature ($9\pm 2^{\circ}\text{C}$) for a period of twenty week in high density polyethylene bag (gauge size 0.03 μm). They resulted as the storage time further increases to 8 weeks, there was a continuous increase in the total plate count particularly at the room temperature. A similar trend was observed when the extrudates were stored at 12, 16 and at 20 weeks.

Balfour *et al.*, (2014) studied the development and quality evaluation of extruded fortified corn snack. Extruded fortified corn snack was developed by single type screw extruder using Corn Meal (CM), Oat Meal (OM) and Whey Protein Concentrate (WPC). The studies were conducted on incorporation of different ratios of CM, OM and WPC used and shelf life study was conducted for two months. Three different ratios of CM, OM and WPC were taken in the proportion of (90:7:3) for the first (80:16:4) second and (70:25:5) third treatment. Spinach and mint leaves were used for flavoring and seasoning. Physico-chemical and sensory analysis of the samples were evaluated. During storage it was observed that moisture content of the sample showed slight increase whereas there was a slight decrease in

all the other proximate analysis. But it was observed that all the proximate parameters were increased from the control sample to the different treatments. Among the treatments the one with 80% and 70% CM were found nutritive. Depending upon the sensory attributes also the sample having 80% CM was found satisfactory for storage and is the most acceptable sample. Therefore the snack developed is a high fiber low calorie snack which can be recommended to the diabetic and obese people.

Gaur and Visvanathan, (2015) studied the iron bioavailability, storability and sensory evaluation of iron fortified extruded snacks intended to alleviate iron deficiency in indian children. Finger millet added with fortifying agents extruded was developed and stored at room temperature in low-density polyethylene (gauge 83 μm) and aluminium bags (gauge 36 μm) with or without nitrogen flushing and they resulted the Products fortified with NaFeEDTA (sodium iron ethylene diamine tetraacetate) and packed in aluminium foil with nitrogen flushing were found optimal in terms of iron bioavailability, storability and consumer acceptability.

Literature survey indicated that limited reports are available on extrusion cooking of tuber crops. The functional, nutritional properties of the tuber crop based extrudates is also very scarce. It is therefore planned to undertake the research work on the development of tuber crops based extrudates.

III. MATERIAL AND METHODS

This chapter deals with the material and equipments used, methodology followed and experimental techniques adopted in conducting various experiments. The research work on Development of arrowroot, lesser yam and potato based extrudates was undertaken. To investigate the possibility of making extrudates using potato as base material, experiment was formulated for arrowroot, lesser yam and potato in different proportions. The study was involved a series of investigation covering the determination of functional, nutritional properties of flour compositions, preparation of extrudates using various treatments, temperatures of extrusion and screw speeds; functional, nutritional, textural and sensory properties of finished product and optimization of extrudates. The extrusion cooking was conducted in Extrusion Cooking Laboratory of Department of Agricultural Process Engineering. The packaging and storage study experiments were conducted in NAIP Lab of Department of Agricultural Process Engineering. Investigation on its nutritional and functional properties, the experimental work was carried out in the Department of Agricultural Process Engineering (APE), College of Agricultural Engineering and Technology (CAET), Dapoli. Nutritional analysis was carried out in the laboratory of the Department of Agricultural Chemistry and Soil Science, College of Agriculture, Dapoli.

3.1 Development of flours from Arrowroot, Lesser yam and Potato tubers

Tuber crops i.e. Arrowroot, Lesser yam and Potato were used for present study. Arrowroot and Lesser yam tuber crops were procured from the university farm (Central Experimental Station, Wakwali), Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli. Potato Tuber crops were purchased from local market of Dapoli. These tuber crops are stored at room temperature for further study. These tuber crops i.e. Arrowroot, Lesser yam and Potato as shown in Figure 3.1 (a), 3.1 (b) and 3.1 (c) respectively.

3.1.1 Arrowroot flour

The arrowroot washed with clean water, outer layer of the tuber were peeled and sliced (5-6 mm thick). Arrowroot slices were put into convective dryer. The drying was carried out in a tray dryer (Make: M/s Rotex Industries, Pune) having capacity 60 kg. Fig. 3.2 shows the dryer used for the study. There were 24 no. of trays inside the tray dryer. The size

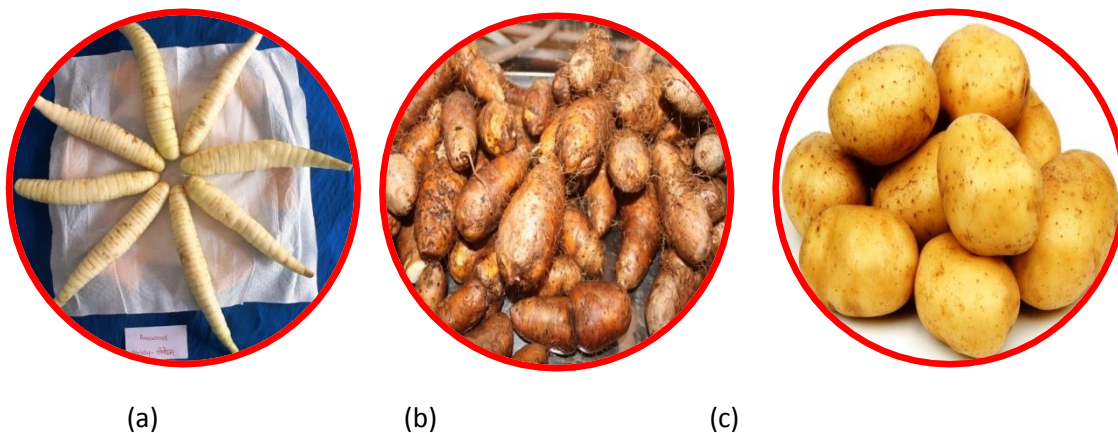


Fig. 3.1: Tuber crops (a) Arrowroot; (b) Lesser yam; (c) Potato



Fig. 3.2: Dryer used for drying the tuber crops slices.



Fig. 3.3: Pulverizer for size reduction of Arrowroot, Lesser yam and Potato tuber crop

Slices

of the tray was 54 cm × 50 cm × 2 cm. The temperature of the drying was kept as 60±1°C for 7-8 hrs up to 8-9 % MC (db). Moisture content of arrowroot slices were determined by using hot air as per AOAC (2010) as per the following Eq. (3.1);

$$\text{Moisture Content (d.b.)\%} = \frac{W_1 - W_2}{W_2} \times 100 \quad \dots(3.1)$$

Where, W_1 = weight of sample before drying, g

W_2 = weight of bone dried sample, g

The weight loss during drying was measured by three number of perforated trays placed at three different locations in tray dryer i.e. top, middle and lower side of the dryer. Moisture content (% db) verses drying time (min) and drying rate (kg of water removed/kg of dry matter/h) with respect to moisture content was determined for drying of arrowroot tuber crop slices. Moisture content verses drying time (min) was also determined from the experimental data of arrowroot tuber crop slices. The slices taken out from dryer and allow to cool at ambient temperature and milled upto 42.76 μ size particles in the pulverizer (Fig. 3.3). Fig. 3.4 shows the flow chart of preparation of Arrowroot flour.

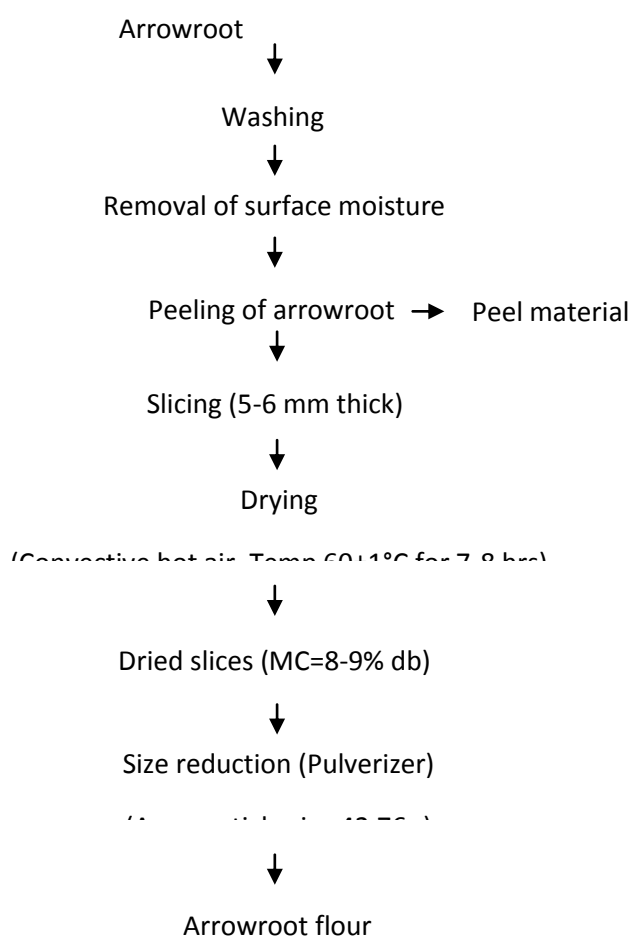


Fig. 3.4: Flow chart for preparation of Arrowroot flour

3.1.2 Lesser yam flour

The lesser yams were washed and peeled and root heads were removed from the tuber. This peeled yam tubers were boiled in hot water up to 45 min to increase the moisture content from 316.62 to 354.5% (db). After boiling, the boiled yam tubers were cut into slices (3-4 mm thick). These slices were placed into the convective hot air dryer (Fig. 3.2) and dried at temperature $60\pm1^{\circ}\text{C}$ for 6-9 h upto 9-10 % MC (db), dried slices moisture content was determined as per the procedure given in section 3.1.1 in eq. 3.1 and then slices were taken out from the dryer and allowed to cool at ambient temperature and milled using pulverizer (Fig. 3.3) up to average particle size 40.00μ to make flour (Adegunwa *et al.*, 2011). Moisture content (% db) verses drying time (min) and drying rate (kg of water removed/kg of dry matter/h) with respect to moisture content was determined for drying of lesser yam tuber crop slices. Moisture content verses drying time (min) was also determined from the experimental data of lesser yam tuber crop slices. Fig. 3.5 shows the flow chart of preparation of Lesser yam flour. The lesser yam flour was developed as per the procedure described Adegunwa *et al.*, 2011).

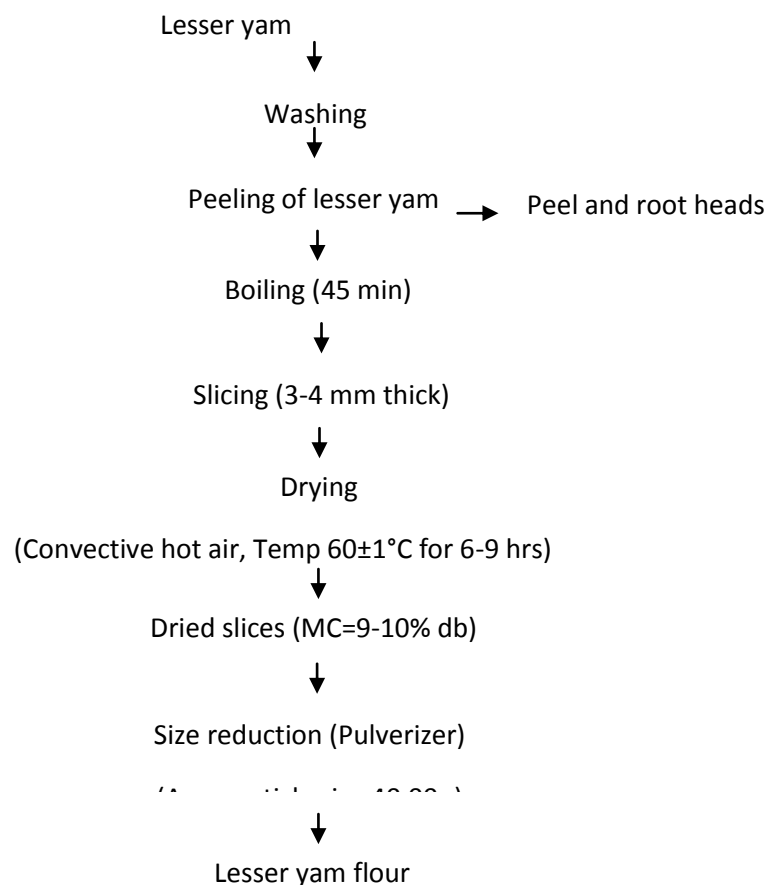


Fig. 3.5: Flow chart for preparation of Lesser yam flour

3.1.3 Potato flour

The potato flour was prepared as per the procedure described by Darvishi *et al.*, 2013. Fig. 3.6 shows the flow chart of preparation of Potato flour. Potatoes were washed, peeled, sliced (2-4mm thick). These slices were boiled in hot water at temperature of 100°C for 5 min to increase its moisture content from 317.2 to 376.19% (db) with addition of potatoes were immersed in a sodium meta-bi-sulphite solution (0.1% w/w) to prevent browning during drying. This blanched slices were dried in convective hot air dryer (Fig. 3.2) at drying temperature $60\pm1^{\circ}\text{C}$ for 8-9 hrs upto 6-7 % MC (db), dries slices moisture content was determined as per the procedure given in section 3.1.1 in Eq. 3.1.

Moisture content (% db) verses drying time (min) and drying rate (kg of water removed/kg of dry matter/h) with respect to moisture content was determined for drying of potato tuber crop slices. Moisture content verses drying time (min) was also determined from the experimental data of potato tuber crop slices. The slices were taken out from the dryer and allowed to cool at ambient temperature and grounded to a particle size 27.28μ by using pulverizer (Fig. 3.3) to make flour (Darvishi *et al.*, 2013).

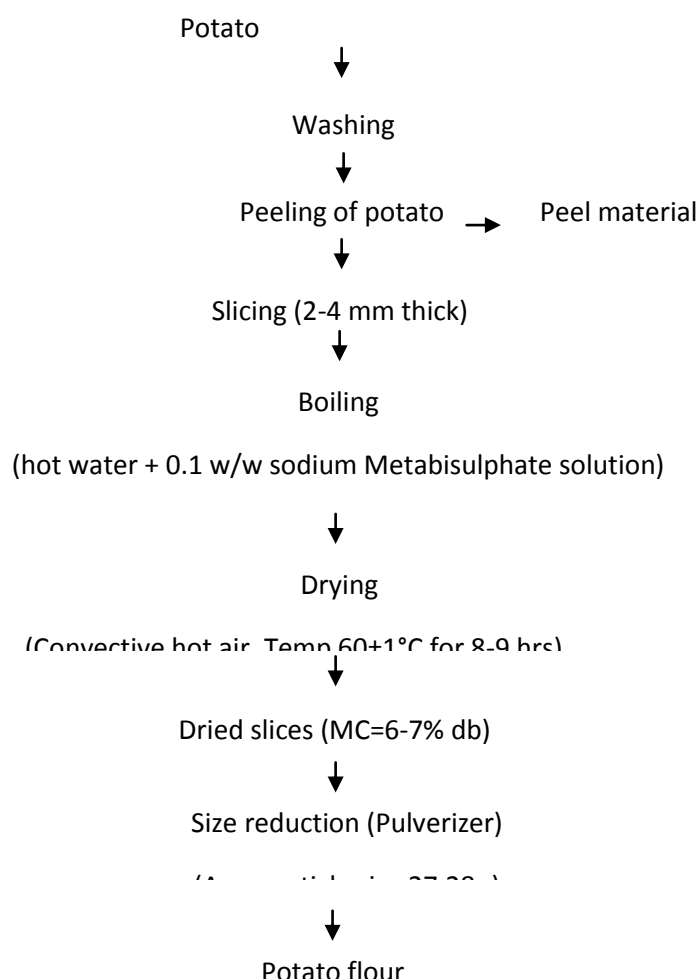


Fig. 3.6: Flow chart for preparation of Potato flour.

3.2 Particle size analysis of tuber crop flours

The particle size distribution of treatment combination of flours was performed by using Image analysis system by using KOZO KXP 300 digital microscope with cold light source LED ring (made: China). Small quantity of developed flour of all treatment combinations was taken on the glass slide with sample was exposed to the microscope. The images of the particles obtained by Kozo stereo zoom microscope was compared calibrated with the scale by using image analysis software Biovis IP, 2000 with 3 MPS camera. The software directly gives the particle size distribution within 0 to 2.5; 2.6 to 5; 5.1 to 10; 10.1 to 30; and 30 microns and above. The software also gives the average particle (μ) of the flour samples. The average particle size of the flour was determined at ambient temperature $22\pm1^{\circ}\text{C}$ for all treatment flour combinations. The images were taken for the replicated samples also. Figure 3.7 shows the image analyzer used for image analysis of arrowroot, lesser yam and potato tuber crop slices flour.



Fig. 3.7: Image Analysis System for particle size distribution

3.3 Determination of Physico-chemical (nutritional and functional properties) of Arrowroot, Lesser yam and Potato flours and their combinations.

The arrowroot: lesser yam: potato flours prepared as discussed in section 3.1.1, 3.1.2 and 3.1.3 were mixed at the ratio of 100:00:00, 00:100:00, 00:00:100, 00:50:50, 10:40:50, 20:30:50, 30:20:50, 40:10:50 and 50:00:50 respectively. Table 3.1 shows the flour combinations of material used.

3.3.1 Nutritional properties of flour combinations

The nutritional properties of the flours include protein, fat, fiber, ash, moisture content and carbohydrates. These nutritional properties were determined by following procedure.

3.3.1.1 Moisture content

The initial moisture content of flour samples for all treatments F1 to F9 of arrowroot, lesser yam and potato flours were determined by using hot air oven method (AOAC, 2010). The 10 g flour was taken in the moisture box. The moisture box was kept in hot air oven at $105^{\circ}\text{C}\pm 1$ for 24 h. The final weight of flour after 24 h was recorded. The moisture content of the treatments combinations (F1-F9) was replicated 3 times. The average value of moisture content is reported. The moisture content was calculated as per the section given in 3.1.1 in eq. (3.1)

Table 3.1: Flour combinations of raw material used

Treatment	Arrowroot	Lesser yam	Potato	Total
F1	100	0	0	100
F2	0	100	0	100
F3	0	0	100	100
F4	0	50	50	100
F5	10	40	50	100
F6	20	30	50	100
F7	30	20	50	100
F8	40	10	50	100
F9	50	0	50	100

3.3.1.2 Protein content

The protein content of flour samples for all treatments F1 to F9 of arrowroot, lesser yam and potato flours were determined by Microkjeldhal method (Ranganna, 1986). Around 0.25 g flour was taken for the analysis. 15 ml H_2SO_4 was added in the flour and solution was allowed to predigest for 14 h (overnight). After digestion of sample 5 ml H_2O_2 was added to it and shake the mixture vigorously up to colour of sample change to colour-less sample. Colour-less sample was makeup up to volume 25 ml. The makeup sample (25 ml) was taken as volume of aliquot. After digestion procedure is completed, the sample was allowed for distillation. Automatic distillation unit provided with receiver flask contained 20 ml boric acid indicator. The mixture of 10 ml colourless sample solution (aliquot) and 10 ml water was taken for distillation with flushing the NaOH as 25 ml in nitrogen distillation unit. The outlet tube of distillation unit assembly was properly submerged into the indicator. Mixing chamber of the assembly was heated for 6 minute or until the colour of indicator solution was changed from pink to green. The experiment was replicated for 3 times. The distillate sample was titrated against 0.01N H_2SO_4 . The average value of protein content is reported. The protein content was calculated by using following formula (3.2);

$$\% \text{ Protein} = \frac{(\text{Sample titre} - \text{Blank titre}) \times \text{Normality of } H_2SO_4 \times 0.014 \times \text{vol. of aliquot} \times 6.25 \times 100}{\text{Weight of sample taken}} \dots (3.2)$$

3.3.1.3 Fat content

Fat content of individual raw flour samples for all treatments F1 to F9 of arrowroot, lesser yam and potato flours were determined by soxhlet fat extraction system (AOAC, 2010) by Soxhlet apparatus (Make: Elico, Hyderabad). In this method, initially weight of empty flask was weighed. 2 g flour was wrapped in filter paper. The sample with filter paper was kept in siphoning tube and condenser was fixed above it and siphoned for 9-12 times with the petroleum ether in soxhlet apparatus. After removing assembly, evaporation of petroleum ether was allowed by heating round bottom flask. Residue remained at the bottom of the flask and was reweighed with flask. The quantity of residue was determined as fat content of flour. The experiment was replicated for 3 times. The average value of fat content is reported. The fat content was calculated by using following formula (3.3);

$$\% \text{ Fat content} = \frac{\text{Final wt.} - \text{Initial wt.}}{\text{Wt. of sample}} \times 100 \dots (3.3)$$

3.3.1.4 Fiber content

The fiber content flour samples for all treatments F1 to F9 of arrowroot, lesser yam and potato flours were determined by the fat free sample available in filter paper from fat extraction method (Ranganna, 1986). The filter paper and fat free residue was kept in the oven for 105⁰ C for 5-6 hours. Around 2 g sample from oven was taken into 600 ml beaker and boiled, 200 ml 1.25% H₂SO₄ was added to it. The beaker containing solution was placed on hot plate for 30 minute. After heating residue from beaker was filtered through filter paper and rinsed beaker with 50 to 75 ml boiling water for three times. The filtered residue from filter paper was dried by convective hot air drying for 2-3 h at 130±1°C. The dried residue from convective hot air dryer was transferred to 600 ml beaker and boiled, 200 ml 1.25 % NaOH was added to it and boiled for 30 more minutes on hot plate. After heating residue from beaker was filtered through filter paper and rinsed beaker with 50 to 75 ml boiling water for three times. The filtered residue from filter paper was dried by convective hot air drying at 130⁰ C for 2 h. The dried residue was weighed after cooling and weight was noted. The weighed residue was transferred to crucible in hot air oven and ignited for 30 minutes at 600 ± 2⁰ C and reweighed after cooled in desiccator and weight was recorded. The experiment was replicated for 3 times. The average value of crude fiber content is reported. The crude fiber content was calculated by using following formula (3.4);

$$\% \text{ Fibre} = \frac{\text{weight of residue with crucible} - \text{weight of ash with crucible}}{\text{weight of sample}} \times 100 \dots (3.4)$$

3.3.1.5 Ash content

Ash content of flour samples for all treatments F1 to F9 of arrowroot, lesser yam and potato flours were determined by using muffle furnace. Five gram of flour was taken in a crucible. Weight of crucible and flour was recorded and kept in muffle furnace at 650 ± 2⁰ C for 4-5 h till constant weight was achieved. It was observed for three constant readings. The crucible was cooled in desiccators and final weight of ash and crucible was recorded. The experiment was replicated for 3 times. The

average value of ash content is reported. The ash content was calculated by using following formula (3.5);

$$\text{Ash content, \%} = \frac{W_2 - W}{W_1 - W} \times 100 \quad \dots(3.5)$$

Where,

W = weight of crucible, g;

W₁ = weight of crucible and flour, g; and

W₂ = weight of crucible with ash, g.

3.3.1.6 Carbohydrates

Carbohydrate content for samples of all treatments F1 to F9 of arrowroot, lesser yam and potato flours were determined was determined by subtracting the total sum of protein, fiber, ash and fat from the total dry matter (Vengaiah *et al.*, 2013). The carbohydrate was calculated by using following formula (3.6);

$$\text{Carbohydrates} = 100 - (\text{Protein} + \text{Fat} + \text{Fibre} + \text{Ash} + \text{Moisture content}) \quad \dots(3.6)$$

3.3.2 Functional properties of flour combinations

The functional properties of flours include water absorption capacity, oil absorption index, bulk density, flour dispersibility and yellowness index. The functional properties of flours were determined by procedure described as below.

3.3.2.1 Water Absorption Capacity (WAC) (ml/g)

The water absorption capacity of flours was determined by the method of Chandra and Samsher (2013) for all samples from treatments F1 to F9 for arrowroot, lesser yam and potato flours. 1 g of sample was mixed with 10 ml distilled water in centrifuge tube and allow to stand at ambient temperature (30 ± 2°C) for 1h, the mixture was centrifuged by using centrifuge (Make: M/s Remi Electrotechnik limited, Thane, India; Model: R- 8C BL) for 30 min at 2000 rpm. The sediments were weighed after complete removal of the supernatant. The experiment was replicated for 3 times. Figure 3.8 shows the centrifuge used for centrifugation of water and flour sample mixture. The average value of WAC is reported. The WAC was calculated by using following formula (3.7);

$$\text{WAC} = \frac{(W_2 - W_1)}{W_0} \times 100 \quad \dots(3.7)$$

Where:

W₀ = the weight of the sample, g;

W_1 = the weight of centrifuge tube plus sample, g; and

W_2 = the weight of centrifuge tube plus the sediments, g.



Fig. 3.8: Centrifuge for water and oil absorption capacity of flour

3.3.2.2 Oil Absorption Capacity (OAC) (ml/g)

The oil absorption capacity of flour was determined by the method of Shad *et al.*, 2012 for all samples from treatments F1 to F9 for arrowroot, lesser yam and potato flours. 1 g of sample was mixed with 10 ml refined soybean oil and was kept at ambient temperature for 30 min and centrifuged for 30 min at 2000 rpm. Fig. 3.8 shows the centrifuge for oil absorption capacity of flour. Oil absorption capacity was expressed as percent oil bound per gram of the sample. The sediments were weighed after the complete removal of supernatant oil. The experiment was replicated for 3 times. The average value of OAC is reported. The OAC was calculated by using following formula (3.8);

$$OAC = \frac{(W_2 - W_1)}{W_0} \times 100 \quad \dots(3.8)$$

Where:

W_0 = the weight of the sample, g;

W_1 = the weight of tube plus sample, g; and

W_2 = the weight of the tube plus the sediments, g.

3.3.2.3 Bulk Density (BD) (g/cm³)

The bulk density of flour was determined according to the method described by (Vengaiah *et al.*, 2013) for all samples from treatments F1 to F9 for arrowroot, lesser yam and potato flours. A graduated measuring cylinder of 5 ml was weighed and flour sample filled in to it by constant tapping until there was no further change in volume. The cylinder with the flour sample was weighed and the difference in weight was determined. The experiment was replicated for 3 times. The average value of bulk density is reported. The bulk density was calculated by using following formula (3.9);

$$\text{Bulk density } \left(\frac{\text{g}}{\text{cm}^3} \right) = \frac{\text{Wt.of cylinder after filling sample,g}-\text{Wt.of empty cylinder,g}}{\text{Volume of sample after tapping,cm}^3} \quad \dots(3.9)$$

3.3.2.4 Flour Dispersibility (FD) (%)

The flour dispersibility of flour samples were determined according to the method described by Airani (2007) for all samples from treatments F1 to F9 for arrowroot, lesser yam and potato flours. 10 g of flour sample was taken in 100 ml measuring cylinder. Distilled water was added to make the volume of 100 ml the mixture was stirred vigorously and allowed to settle for three hours. The volume of settled particles at the bottom of the mixture was subtracted from 100 and the difference was reported as percentage dispersibility. The experiment was replicated for 3 times. The average value of flour dispersibility was reported.

3.3.2.5 Yellowness Index (YI)

A colour of flour sample was measured by using Hunter Lab colorimeter (Make: Hunter Associate Laboratory, USA; Model: Colourflex 45/0). The colour measuring device was calibrated with standard white and black tile. The yellowness index was measured for all samples from treatments F1 to F9 for arrowroot, lesser yam and potato flours. The flour was taken into a glass sample holder of the color meter. The sample holder was kept on the aperture of the colour measuring device in such a way that light should not pass through it. 20 g sample was placed in the sample glass holder. The test was conducted for each treatment. The L, a and b values of the sample was determined. It represents the colour in L, a and b value. Degree of lightness or darkness of the samples was represented by "L" value, redness to greenness by "a" value and yellowness to blueness by "b" value on hunter scale. The experiments were replicated for 3 times. The average value of yellowness index is reported. Fig. 3.9 shows the Hunter lab colorimeter and Hunter lab colour system of arrowroot, lesser yam and potato flours

Yellowness index (YI) of L, a and b values was determined (Pankaj *et al.*, 2012). Yellowness index was determined by using Eq. (3.10);

$$YI = \frac{142.87b}{L} \quad \dots(3.10)$$

Where:

L= Degree of lightness or darkness

a = Redness to greenness

b = Yellowness to blueness



Fig. 3.9: Hunter Lab Colorimeter

3.3.3 Statistical analysis of data on flour combinations

ANOVA with replicated factor was done. The significant and non-significant treatment was judged with the help of F (variance ratio) table and t-test. The significant difference between the means was tested against the critical difference at $p \leq 0.01$.

3.4 Study the influence of composition and extrusion parameters on the extrudates.

The arrowroot, lesser yam and potato flours combinations were used for extrusion cooking. The extrusion parameters include the extrusion temperature (130, 150 and 170°C) and screw speed (330, 360 and 390). The effect of this flour combinations, extrusion temperature and screw speed on nutritional and functional properties were studied.

3.4.1 Experimental design and treatment combinations.

The final moisture content of Arrowroot flour, Lesser yam flour and Potato flour were 5.81, 8.56 and 8.07% (db). The moisture content of the flour was adjusted by adding 3 ml Kokum (*Garcinia Indica*) Liquid Concentrate at 40°B in 7 ml water to make it up to 10 ml. Kokum Liquid Concentrate

was added during extrusion cooking to reduce the bitter taste of final extrudates due to incorporation of lesser yam. The liquid diluted is added to the flour mixture of 100g to make the moisture content 13-14% (db) for each treatment. The flour mixture and the liquid concentrate were well mixed with the help of pan and an agitator. The mixture was sieved through the 2 mm sieve for breaking the lumps formed during mixing. The final moisture content of all the samples was 15% (db). The moisture content of the samples was determined by AOAC, 2010 (Eq. 3.1). These samples were exposed to extruder temperature 130, 150 and 170°C and screw speed 330, 360 and 390 rpm were used to prepare the extrudates from flour combinations of treatment (T1 to T6).

Table 3.2: Flour combinations for extrusion cooking

Treatment	Arrowroot (%)	Lesser yam (%)	Potato (%)	Total (%)
T1	0	50	50	100
T2	10	40	50	100
T3	20	30	50	100
T4	30	20	50	100
T5	40	10	50	100
T6	50	0	50	100

The Arrowroot flour: Lesser yam flour: Potato flour were mixed at the ratio of 100:00:00, 00:100:00, 00:00:100, 00:50:50, 10:40:50, 20:30:50, 30:20:50, 40:10:50 and 50:00:50 respectively. Table 3.2 shows the flour combinations for extrusion cooking.

3.4.2 Extrusion cooking of tuber crop based extrudates

Extrusion cooking of samples was performed using a co-rotating twin-screw extruder (M/s Basic Technology Pvt. Ltd., Kolkata, India). The length-to-diameter (L/D) ratio of the extruder was 8:1. The main drive of extruder was provided with a 7.5 HP motor (400 V, 3Φ, 50 cycles). The output shaft of worm reduction gear was provided with a torque limiter coupling. The barrel of the extruder received the feed from a co-rotating variable speed feeder. The barrel was provided with two electric band heaters and two water cooling jackets for circulation of tap water. A temperature sensor was fitted on the front die plate, which was connected to temperature control unit placed on the control panel of barrel. The die was required to be fixed on the face of barrel by a screw nut tightened by a special wrench provided. The twin screw extruder was kept on for 45 min to stabilize the set temperatures and samples were then poured in to feed hopper. The rpm of feed rate of the sample was 40 rpm. The die diameter was selected at 5 mm and shape of opening of die was cylindrical. Length to diameter ratio of die was 2.5 cm: 0.05 cm. Temperature range was 130, 150 and 170°C, screw speed was 330, 360 and 390 rpm. The extrusion cooking was performed for flour

combinations T1 to T6 for extrusion temperature 130, 150 and 170°C and screw speed 330, 360 and 390 rpm. Direction of rotation of screws was counter rotating. The product was collected at the die end. Collected product was kept at $60\pm0.5^{\circ}\text{C}$ in dryer (M/s: Basic Technology Private Ltd., Kolkata, India) for 1 h duration to remove extra moisture from the product. The samples were packed in polythene bags for further analysis. Figure 3.10 shows the twin screw extruder used for extrusion cooking.

3.4.3 Functional properties of extrudates

The functional properties of extrudates are expansion ratio, bulk density, water absorption index (WAI), water solubility index (WSI) and hardness were determined as per the procedures described as below.



Fig. 3.10: Twin screw extruder

3.4.3.1 Expansion ratio (ER)

The expansion ratio of extrudates was determined for extrudates flour samples for treatments T1 to T6, temperature of extrusion 130 to 170°C and screw speed 330 to 390 rpm as per the procedure described by Pathania *et al.*, (2013). The ratio of the diameter of the extrudate and the diameter of the die was used to express the expansion of the extrudate. The diameter of the extrudate was determined as the mean of random measurements made with a

vernier caliper (0.01cm). The extrudates cut into 8-10 cm pieces. The diameter of extrudates were determined at 5 different locations along the length (d) of extrudates and against 90° to that length (d') as given in Fig 3.11. The average value of diameter (Eq. (3.11)) at these 5 locations was reported as diameter of extrudates. The experiment was replicated 10 times. The die diameter of extrudates was 5mm. Expansion ratio calculated by Eq. (3.12);

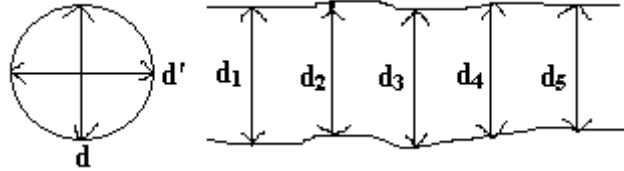


Fig. 3.11: Diameter of extrudates

$$\text{Average value } (d_{\text{avg}}) = \frac{(d_1 + d'_1) + (d_2 + d'_2) + (d_3 + d'_3) + (d_4 + d'_4) + (d_5 + d'_5)}{10} \quad \dots(3.11)$$

$$\text{Expansion ratio} = \frac{\text{Average value } (d_{\text{avg}})}{\text{Die Diameter}} \quad \dots(3.12)$$

3.4.3.2 Bulk density (BD) (g/cm³)

Bulk density (g/cm³) was calculated for extrudates samples for treatments T1 to T6, temperature of extrusion 130 to 170°C and screw speed 330 to 390 rpm as per the procedure described by (Stojceska *et al.*, 2008). Bulk density was calculated from the mass of extrudates, length of extrudates and average diameter (d_{avg}) of extrudates from eq. (3.11). Bulk density (g/cm³) determined by using Eq. (3.13);

$$\text{BD} = \frac{4m}{\pi \times d_{\text{avg}}^2 \times L} \quad \dots(3.13)$$

Where:

m = Mass of extrudates, g;

L = Length of extrudates, cm; and

d_{avg} = Average diameter of individual extrudates, cm.

3.4.3.3 Water Absorption Index (WAI) (g/g)

The WAI of extrudates were determined for extrudates flour samples for treatments T1 to T6, temperature of extrusion 130 to 170°C and screw speed 330 to 390 rpm as per the procedure described by Stojceska *et al.*, (2008). The 1 g ground extrudate sample was suspended in 10 ml of water at room temperature for 30 min, the mixture is gently stirred during this period and then centrifuged at 3000 g for 15 min. The supernatant was decanted into an evaporating dish of known weight. The WAI was the weight of water obtained after removal of the supernatant per unit weight of original dry solids. WAI calculated by using Eq. (3.14);

$$WAI = \frac{\text{Weight gain by gel, (g)}}{\text{Dry weight of extruded, (g)}} \quad \dots(3.14)$$

3.4.3.4 Water Solubility Index (WSI) (%)

The WSI of extrudates were determined for extrudates flour samples for treatments T1 to T6, temperature of extrusion 130 to 170°C and screw speed 330 to 390 rpm as per the procedure described by Stojceska *et al.*, (2008). WSI was determined as per procedure given in section 3.6.4.3. WSI was the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample. WSI calculated by using Eq. (3.15);

$$WSI (\%) = \frac{\text{Weight of dry soild in supernatant}}{\text{Dry weight of extruded}} \times 100 \quad \dots(3.15)$$

3.4.3.5 Hardness of extrudates (HR) (g)

The peak force as an indication of hardness was measured with Texture Analyzer (Model: Texture Pro CT V1.3, Make: Ametet (main)), M/s Brookfield Engineering Labs, Inc., USA) using TA3/100 probe. The diameter of probe was 0.5 cm. The test speed was 0.5 mm/s. The depth of penetration of probe in sample was 4 mm and 50 kg load cell was used. Extruded sample for extrudates flour samples for treatments T1 to T6, temperature of extrusion 130 to 170°C and screw speed 330 to 390 rpm was placed at the base of the sample holder of the texture analyzer and compression force was applied on it. Trigger load was provided 6g. The peak force which was required to break the extruded sample was recorded as hardness of extruded. The equipment gives the force deformation characteristics of the extrudates by using Texture Exponent 32 software program (version 3.0). Figure 3.12 shows the texture analyzer used for measuring the hardness of extrudates.



Fig. 3.12: Brookfield Texttrue Analyzer (CT3) used for measuring hardness of extrudates.

3.4.4 Nutritional Properties and colour measurement of extrudates

The extruded prepared using the various treatment combinations i.e. T1, T2, T3, T4, T5 and T6 of flours, temperature of extrusion 130, 150 and 170°C and screw speed 330, 360 and 390 rpm. The extrudates prepared as per the above treatment combination were used for the nutritional properties analysis. The extrudates prepared using above mentioned treatment combinations was grounded to an average particle size of 1.30 μ . The extrudate powders were equilibrated to 8% (db) MC in desiccators by using the saturated solution of salt NaCl at the atmospheric temperature to maintain its RH 75%. These flour samples were used as extruded sample flour.

The nutritional analysis i.e. protein, fat, fibre, ash, moisture and carbohydrates content of the extrudate flour samples of treatments T1, T2, T3, T4, T5 and T6 at 330, 360, 390 rpm screw speed and 130, 150 and 170°C temperature were determined as per the following standard procedures.

3.4.4.1 Moisture content

The initial moisture content of extrudates flour samples for treatments T1 to T6, temperature of extrusion 130 to 170°C, screw speed 330 to 390 rpm were determined by using hot air oven method (AOAC, 2010) as discussed in section 3.1.1. (Eq. 3.1).

3.4.4.2 Protein content

The protein content of extrudates flour was measured by Microkjeldhal method (Ranganna, 1986) for samples for treatments T1 to T6, temperature of extrusion 130 to 170°C, screw speed 330 to 390 rpm as discussed in section 3.3.1.2.

3.4.4.3 Fat content

Fat content of extrudates flour was determined using soxhlet fat extraction system (AOAC, 2010) by Soxhlet apparatus (Make: Elico, Hyderabad) for samples for treatments T1 to T6, temperature of extrusion 130 to 170°C, screw speed 330 to 390 rpm as discussed in section 3.3.1.3.

3.4.4.4 Fiber content

The fibre content of extrudates flour was determined from the fat free sample available in filter paper from fat extraction method (Ranganna, 1986) for samples for treatments T1 to T6, temperature of extrusion 130 to 170°C, screw speed 330 to 390 rpm as discussed in section 3.3.1.4.

3.4.4.5 Ash content

Ash content of extrudates flour was calculated using muffle furnace for samples for treatments T1 to T6, temperature of extrusion 130 to 170°C, screw speed 330 to 390 rpm as discussed in section 3.3.1.5.

3.4.4.6 Carbohydrates

Carbohydrate content was determined by subtracting the total sum of protein, fibre, ash and fat from the total dry matter (Vengaiah *et al.*, 2013) for samples for treatments T1 to T6, temperature of extrusion 130 to 170°C, screw speed 330 to 390 rpm as discussed in section 3.3.1.6.

3.4.4.7 Yellowness Index (YI)

A colour co-ordinate of flour was measured under Hunter Lab calorimeter for samples for treatments T1 to T6, temperature of extrusion 130 to 170°C, screw speed 330 to 390 rpm as discussed in section 3.3.2.5.

3.4.5 Statistical analysis of extrudates properties

Statistical analysis of SE and CD values for functional properties of extruded samples like expansion ratio, bulk density, water absorption capacity, water solubility index, hardness and yellowness index and nutritional properties of extruded samples like protein, fat, fiber, ash, moisture and carbohydrates were determined and was carried out by SAS 3.0. Recorded data were subjected to statistical analysis by “Analysis of variance” technique. ANOVA with replicated factor was done. The significant and non-significant treatment was judged with the help of F (variance ratio) table and t-test. The significant different between the means was tested against the critical difference at $p \leq 0.01$.

3.4.6 Sensory evaluation

The extrudates for all the treatments (Flour combinations (T1 to T6); Temperature (130, 150 and 170°C); screw speed (330, 360 and 390 rpm)) were mixed with spices (100 g extrudates sample, 10 g chat masala and 5 g vegetable oil). The extrudates were dried in a convective hot air drying at 50°C for 1 h. These samples for each treatment were cut into uniform length 2-3 cm size pieces and placed in the paper dish. These samples were organoleptically tested for different quality attributes like appearance, taste, colour, texture and overall acceptability.



Fig. 3.13: Sensory analysis of samples

Sensory evaluation was performed by a panel of 45 trained judges of various age groups consisted of students, staff and faculty members from the CAET, Dr. BSKKV, Dapoli (MS). Samples were coded using random code A to C11 (54 samples). Panelists were served with salted potato chips, water to break the monotony in taste of the extrudates. Mean sensory scores for quality attributes (appearance, taste, colour, texture) and overall acceptability were recorded in individual sheet and average scores are reported. Figure 3.13 shows the sensory analysis of extrudates.

3.7.6.1 Statistical analysis of sensory evaluation

ANOVA with replicated factor for sensory analysis was done. The significant and non-significant treatment was judged with the help of F (variance ratio) table and t-test. The significant different between the means was tested against the critical difference at $p \leq 0.01$.

3.4.7 Optimization of Responses for Functional and Nutritional properties of tuber crops extrudates

The effect of temperature of the extruder barrel and screw speed on various parameters of functional properties i.e. expansion ratio, bulk density, water absorption index, water solubility index, hardness and colour of the extrudates were assessed by response surface methodology (RSM) as described by Myers (1971). The variables which were found to influence the extrusion process were termed as regression or factors (X_k). The dependant variables were considered as Response Parameters (Y_k). Y_k and X_k were assumed to be correlated with a second order polynomial in the following form. The second order quadratic model was chosen assuming it will provide a good approximation of the relationship Eq. (3.16)

$$Y_k = \beta_{k0} + \sum_{i=1}^n \beta_{ki} X_i + \sum_{i=1}^n \beta_{ki} X_i^2 + \sum_{i=1}^n \sum_{j=i+1}^n \beta_{kij} X_i X_j \quad \dots(3.16)$$

Where,

β_{k0} and β_{ki} are the regression coefficients.

The values of independent variables were coded within -1, 0 and +1. The coding of X_i (actual value of independent variable) in to E_i (coded value) was done by following Eq. (3.17);

$$E_i = \frac{X_i - X_{i(\text{mean})}}{X_{i(\text{mean})} - X_{i(\text{min})}} \quad \dots(3.17)$$

Where,

X_i = Actual value of factor, i;

$X_{i(\text{mean})}$ = The mean of high and low levels of the factor, i; and

$X_{i(\text{min})}$ = Minimum value of factor, i.

The most desirable parameters of the extrudates were to obtain, product of lower bulk density, more expansion ratio, lower hardness, higher water absorption index and higher water solubility index.

The product obtained with the above procedure should have better nutritional properties (protein, fat, fibre and ash) and more overall acceptability by the panelist.

3.5 Packaging and storage of extrudates

The best treatment obtained from better functional, better nutritional and better sensory analysis was used for the packaging and storage study of arrowroot, lesser yam and potato based extruded products. The best treatment obtained during functional, nutritional and sensory analysis was T2 which content proportion of Arrowroot (10%): Lesser yam (40%): Potato (50%) at extrusion temperature was 130°C and screw speed was 390 rpm. 60 g of best treatment extruded sample was taken in three different packaging materials i.e. Polyethylene pouch (100 µ), Polyester pouch (40 µ) and Aluminium foil pouch (50 µ). The details of packaging materials are given in Table 3.3. Figure 3.14 (a), 3.14 (b) and 3.14 (c) shows the packaging materials i.e. Polyethylene pouch, Polyester pouch and Aluminium foil pouch respectively, used for packaging and storage of arrowroot, lesser yam and potato based extruded products for 2 months. Table 3.3 shows the specifications of packaging material for storage of extrudates.

Table 3.3: Specifications of packaging material for storage of extrudates

Sr. No.	Packaging material	Size	Micron (µ)	Capacity
1	Polyethylene pouch	12 cm × 10 cm	100	60 g
2	Polyester pouch	12 cm × 10 cm	40	60 g
3	Aluminium foil pouch	10 cm × 8 cm	50	60 g

A 60 g of extruded sample was filled separately in polyethylene pouch, polyester pouch and Aluminium foil pouch and sealed properly. These packets were kept at ambient condition up to 6 weeks. The stored samples were analyzed every 10 days interval up to 2 months. The observations for the nutritional and functional properties of stored samples were taken during 7 durations (0, 10, 20, 30, 40, 50 and 60 days) i.e. total number of samples for all the trials were, 7 durations × 3 packaging materials × 3 replications = 63 samples of extrudates kept for storage study. The nutritional properties like protein, fat, fiber, ash, moisture content and carbohydrate for the stored samples were determined for each storage duration i.e. 0, 10, 20, 30, 40, 50 and 60 days. The functional properties like expansion ratio, bulk density, water absorption index, water solubility index, hardness and yellowness index for the stored samples were determined for each storage duration i.e. 0, 10, 20, 30, 40, 50 and 60 days.

3.5.1 Nutritional properties of stored extrudates

Protein, fat, fiber, ash content, moisture content and carbohydrates of extruded samples stored in polyethylene pouch, polyester pouch and Aluminium foil pouch pouches was determined for each storage duration period 0, 10, 20, 30, 40, 50 and 60 days as per the procedure described in Section 3.3.1.1 to 3.3.1.6.

3.5.2 Functional properties of stored extrudates

Expansion ratio, bulk density, water absorption index, water solubility index and hardness of extruded samples stored in polyethylene pouch, polyester pouch and Aluminium foil pouch pouches was determined for each storage duration period 0, 10, 20, 30, 40, 50 and 60 days as per the procedure described in Section 3.4.3.1 to 3.4.3.5.



Fig. 3.14: Packaging materials used for storage of extrudates; (a) Polyethylene pouch, (b) Polyester pouch and (c) Aluminium foil pouch.

3.5.3 Statistical analysis of stored extruded sample

Statistical analysis of SE and CD values for nutritional properties of stored sample like protein, fat, fiber, ash, moisture and carbohydrates and functional properties of stored samples like expansion ratio, bulk density, water absorption capacity, water solubility index, hardness and yellowness index were determined for the packed extrudates in polyethylene pouch, polyester pouch and Aluminium foil pouch and stored for 0, 10, 20, 30, 40, 50 and 60 days was carried out by SAS 3.0. Recorded data were subjected to statistical analysis by “Analysis of variance” technique. ANOVA with single factor was done. The significant and non-significant treatment was judged with the help of F (variance ratio) table and t-test. The significant difference between the means was tested against the critical difference at $p \leq 0.01$.

V. SUMMARY AND CONCLUSION

This chapter deals with the summary of the result obtained during the experimental work carried out and the conclusion from the research work.

5.1 Summary

The arrowroot tuber crop slices were dried from an initial moisture content of 124.42% (db) to 7.61% (db). The lesser yam tuber crop slices were dried from an initial moisture content of 361.71% (db) to 9.56% (db). The potato tuber crop slices were dried from an initial moisture content of 243.85% (db) to 6.10% (db).

The nutritional and functional properties of flour combinations (F1 to F9) were evaluated. These flours were mixed Arrowroot: Lesser yam: Potato in the proportion 100:00:00; 00:100:00; 00:00:100; 00:50:50; 10:40:50; 20:30:50; 30:20:50; 40:10:50 and 50:00:50% respectively. The nutritional properties of the flour combinations (F1 to F9) i.e. protein 2.27-5.36%, fat 0.23-0.98%, fiber 0.48-3.86%, ash 1.91-4.14%, moisture content 1.91-4.14% and carbohydrates 79.81-86.66%. ANOVA for all properties were determined for significant difference at $p \leq 0.01$. The functional properties of the flour combinations (F1 to F9) i.e. water absorption capacity 2.46-1.36ml/g, oil absorption capacity 0.63-1.56ml/g, bulk density 2.41-4.31g/cm³, flour dispersibility 24.33-41.33% and yellowness index 21.81-32.16. The effect of incorporation of lesser yam or incorporation of Arrowroot significantly affected ($p \leq 0.01$) on the nutritional and functional properties of the flour composition.

The flour combinations for extrusion cooking were arrowroot, lesser yam and potato in from of 00:50:50, 10:40:50, 20:30:50, 30:20:50, 40:10:50 and 50:00:50. The extrusion temperatures varied between in 130, 150 and 170°C and screw speed ranged from 330, 360 and 390 rpm. Twin screw extruder was used for extrusion by using above process conditions.

Optimum combination of flour composition (T1 to T6), temperature of extrusion (130, 150 and 170°C) and screw speed (330, 360 and 390 rpm) is based on the desirable functional properties of extrudates i.e. lower bulk density, more expansion ratio, higher water absorption index, higher water solubility index and lower hardness, nutritional properties of exterudates i.e. protein, fat, fiber, ash, moisture and carbohydrates and sensory properties of extrudates i.e. appearance, hardness, crispiness, expansion, colour, taste etc.

Extrudates prepared at treatment T2 (Arrowroot: Lesser yam: Potato (10:40:50) at 130°C extrusion temperature and 390 rpm of screw speed) has functional properties i.e.

expansion ratio 3.13, hardness 1460 g, water absorption capacity 4.22 %, bulk density 0.15 g/cm³ and water solubility index 31.3 %.

Extrudates at treatment T2 ((Arrowroot: Lesser yam: Potato (10:40:50) at 130°C extrusion temperature and 390 rpm of screw speed) higher protein 2.8 %, higher fat 1.4 %, higher ash 1.9 %, lower fiber 1.20 % and lower carbohydrate 85.01 %.

The treatment T2 (Arrowroot: Lesser yam: Potato (10:40:50) at 130°C extrusion temperature and 390 rpm of screw speed) had the highest sensory scores i.e. appearance 7.5, colour 7.2, texture 8.5, crispiness 7.4, expansion 7.0 and overall acceptability 7.5 out of 9.

Packaging and storage of this best treatment sample in polyethylene pouch, polyester pouch and aluminium foil pouch. 60 g sample packed in this pouches with help of sealer, and stored at ambient conditions. Nutritional and functional properties analysis of stored sample was done during interval of 0, 10, 20, 30, 40, 50 and 60 days up to 2 months.

Effect of packaging material (Aluminium foil pouch, polyethylene pouch and polyester pouch) and storage durations (0,10, 20, 30, 40, 50 and 60 days) on the nutritional properties of extrudates (Arrowroot: Lesser yam: Potato i.e. 10:40:50) indicated non significant changes ($p \leq 0.01$) in protein, fat, fiber, ash, moisture and carbohydrates of these extrudates during storage.

Effect of packaging material (Aluminium foil pouch, polyethylene pouch and polyester pouch) and storage durations (0,10, 20, 30, 40, 50 and 60 days) on the functional properties of extrudates (Arrowroot: Lesser yam: Potato i.e. 10:40:50) indicated non significant changes ($p \leq 0.01$) in expansion ratio, bulk density, water absorption index, water solubility index and hardness of these extrudates during storage.

Aluminium foil pouch was found to be the best packaging material compared with polyethylene pouch and polyester pouch to store the extrudates up to 60 days. The nutritional properties after 60 days period were protein 2.70 %, fat 1.22 %, fiber 1.06 %, ash 1.83 %, carbohydrates 86.01 % and moisture 6.83 %.

The functional properties of the extrudates packed in the aluminium foil pouch stored at 60 days period had expansion ratio 3.09, water absorption index 4.54 g/g, hardness of extrudates 1658 g, bulk density 0.09 g/cm³ and water solubility index 42.67 %.

5.2 Conclusions

From the above study following conclusions can be drawn.

1. Best quality tuber crop extrudates i.e. Arrowroot: Lesser yam: Potato (10:40:50) at average particle size 27.40 μ and at 13% (db) moisture content extruded at 130°C extrusion temperature and at 390 rpm screw speed by twin screw extruder.
2. The optimum functional properties of extrudates were higher expansion ratio 3.13, higher water absorption index 4.22 %, lower hardness 1460 g, higher water solubility index 31.3% and lower bulk density 0.15 g/cm³. The nutritional properties of optimum level of product were protein 2.8%, fat 1.4%, ash 1.9%, fiber 1.20% and carbohydrates 85.01%. The overall acceptability by sensory panel was appearance 7.5, colour 7.2, texture 8.5, crispiness 7.4, expansion 7.0 and overall acceptability 7.5 out of 9.
3. The tuber crops extrudates Arrowroot: Lesser yam: Potato (10:40:50) can be packed in Aluminium foil pouch (10 cm $\times$ 8 cm) (50 μ) and stored in good conditions at ambient temperature upto 60 days.

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IV. RESULTS AND DISCUSSION

This chapter includes results of experimental observations and discussion based on these results. The data were analyzed and discussed with the appropriate supportive findings from literature. It includes drying of arrowroot, lesser yam and potato tuber crops, nutritional, functional properties of flour combinations and extrudates, textural, sensory properties of extrudates, storage and packaging of best treatment extrudates obtained from optimum conditions, nutritional, functional properties and sensory properties.

4.1 Convective hot air drying of arrowroot, lesser yam and potato tuber crop slices.

The arrowroot tuber crop slices were dried from an initial moisture content of 124.42% (db) to 7.61% (db). The lesser yam tuber crop slices were dried from an initial moisture content of 361.71% (db) to 9.56% (db). The potato tuber crop slices were dried from an initial moisture content of 243.85% (db) to 6.10% (db). It took around 8.25 h, 7.75 h and 9.25 h for drying of arrowroot, lesser yam and potato respectively by tray drying at 60°C. As drying time increases moisture content decreases for all three tuber crops slices. Fig. 4.1 shows moisture content % (db) w. r. t. time (min) of tuber crops i.e. arrowroot, lesser yam and potato slices dried by tray drying at 60°C.

The drying rate decreased from 0.43 to 0.001, 2.52 to 0.006 and 1.79 to 0.02 kg of water removed/kg of dry matter/h for arrowroot, lesser yam and potato respectively. The lesser yam drying rate was highest from arrowroot and potato drying. In arrowroot, lesser yam and potato slices drying the drying process occurred in falling rate period only. Fig. 4.2 shows the Drying rate (kg of water removed/kg of dry matter/h) w.r.t. moisture content % (db) of arrowroot, lesser yam and potato dried by tray drying at 60°C.

4.2 Flour preparation and Particle size distribution

Flour preparation from arrowroot, lesser yam and potato tuber crops and particle size analysis is discussed in section 3.1 and 3.2 of materials and methods.

4.2.1 Flour preparation

Flour preparation is done with help of pulverizer. Fig. 4.3 shows the treatment combination of flours (F1 to F9) for arrowroot, lesser yam and potato tuber flour.

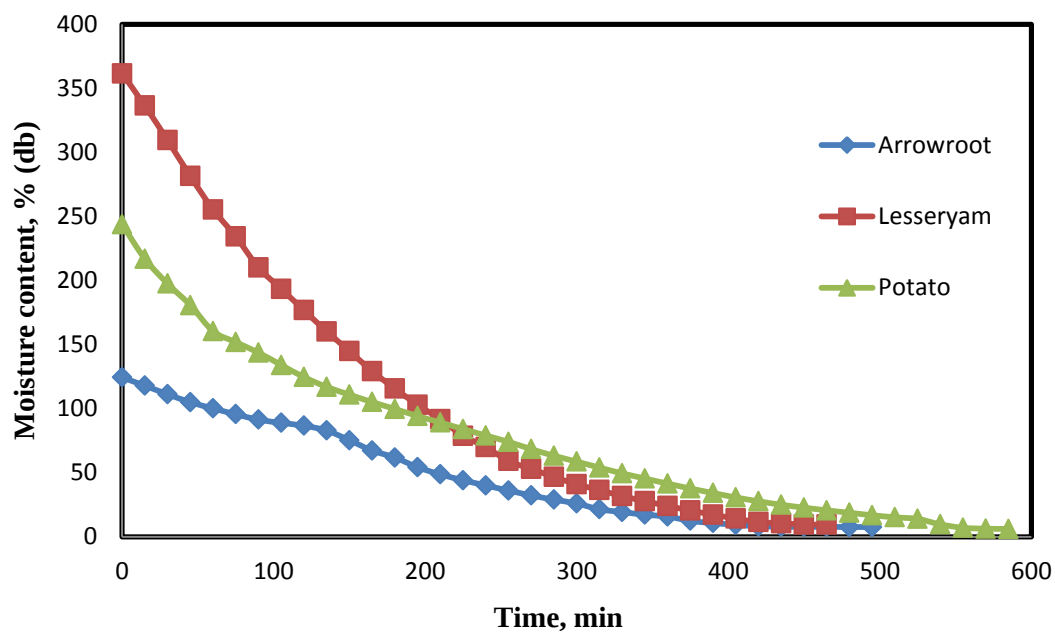


Fig. 4.1: Moisture content % (db) versus Time (min) of tuber crops drying

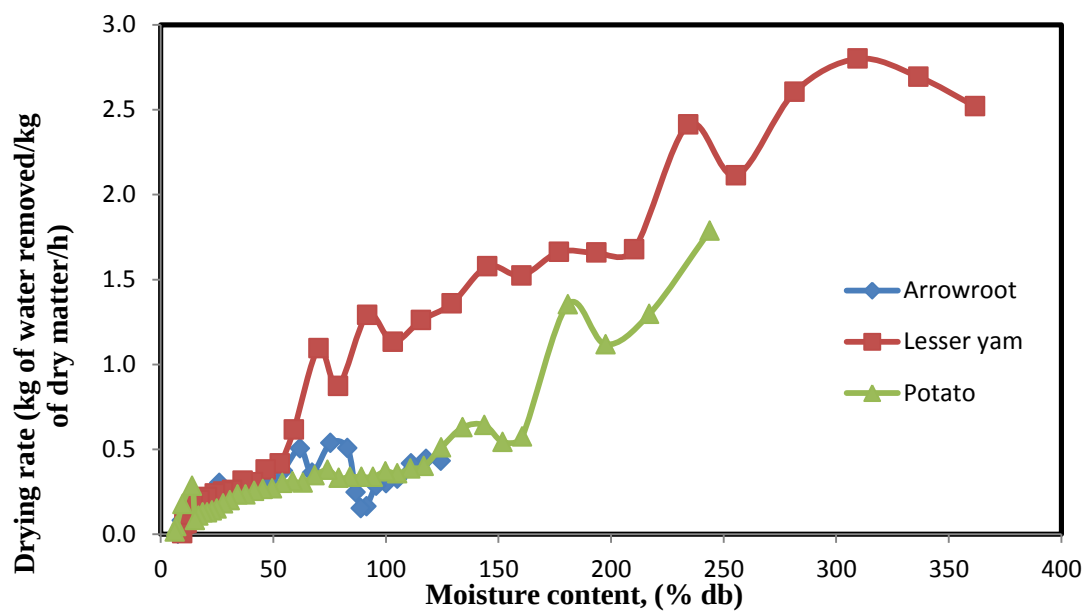


Fig. 4.2: Drying rate (kg of water removed/kg of dry matter/h) versus Moisture content % (db) of tuber crops slices drying (Arrowroot, Lesser yam and Potato)

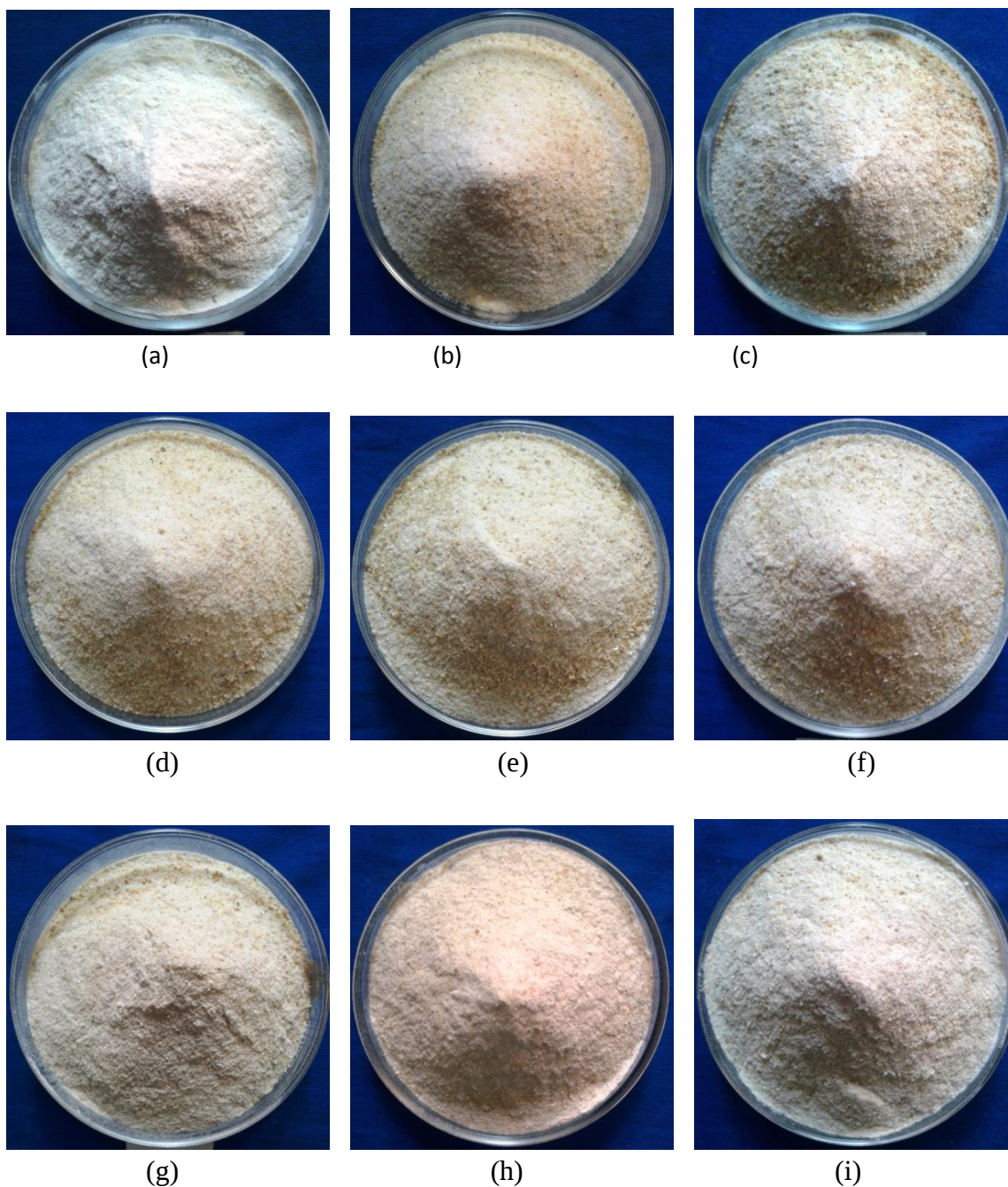


Fig. 4.3: Treatment combination flours (F1 to F9) at 60 °C (a) Treatment F1; (b) Treatment F2; (c) Treatment F3; (d) Treatment F4; (e) Treatment F5; (f) Treatment F6; (g) Treatment F7; (h) Treatment F8; (i) Treatment F9.

4.2.2 Particle size distribution and average particle size of flours (F1 to F9)

Figure 4.4 shows images of treatment combination (F1 to F9) of flours by using image analysis. Table 4.1 shows the particle size distribution of treatment combination (F1 to

F9) flours. Table 4.2 shows the average particle size (μ) determined by using Biovis software for images of treatment combination (F1 to F9) flours.

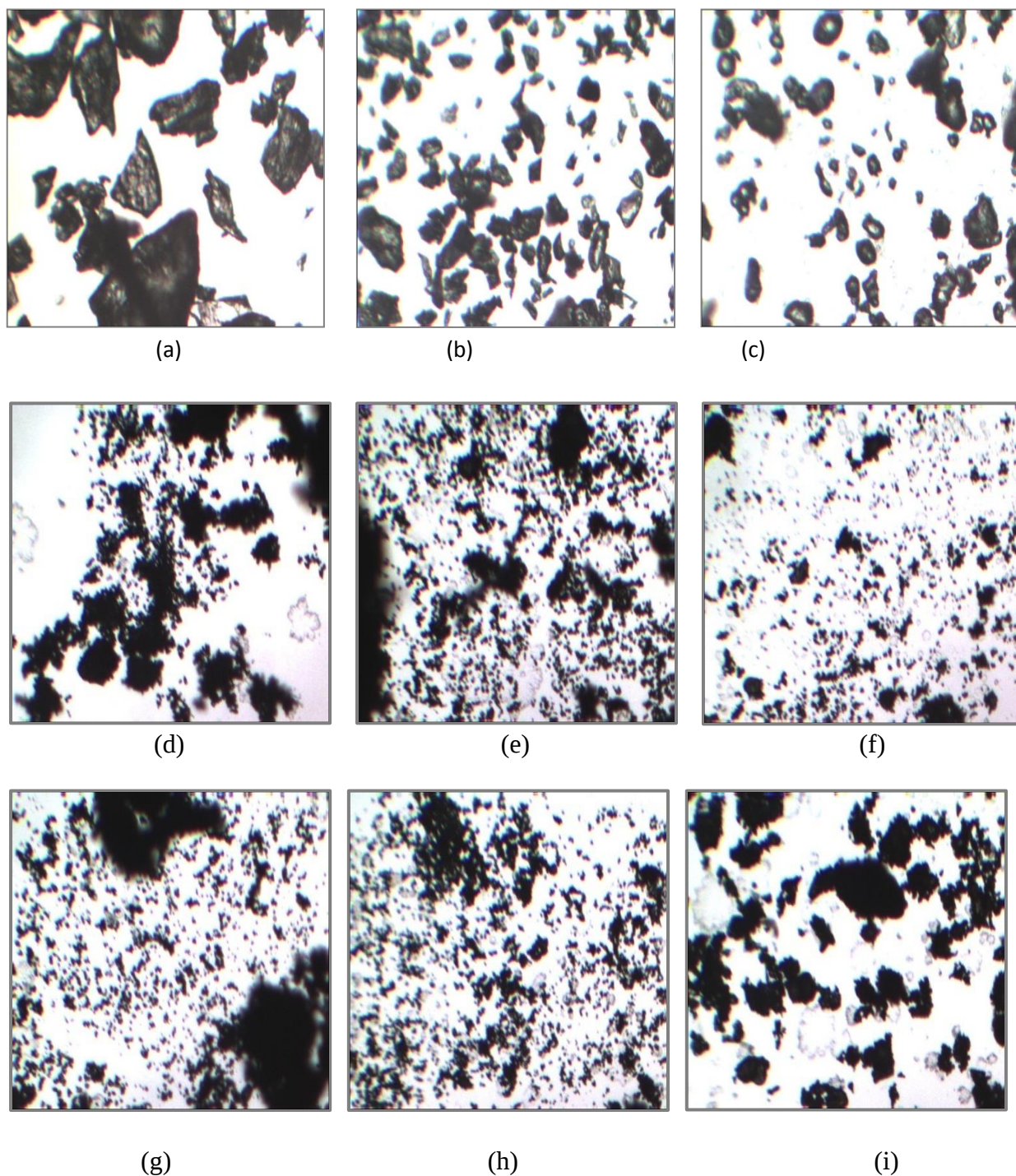


Fig. 4.4: Particle size distribution (F1 to F9) (a) Treatment F1; (b) Treatment F2; (c) Treatment F3; (d) Treatment F4; (e) Treatment F5; (f) Treatment F6; (g) Treatment F7; (h) Treatment F8; (i) Treatment F9.

For treatment F1 number of particales were segergated in 10.1-30 μ (11%) and rest of particales were (89%) in 30 microns and above size. In treatment F2, the particales were segergated 7.6, 2.5, 5.1, 33.33 and 51.28% in (1-2.5 μ), (2.6-5 μ), (5.1-10 μ), (10.1-30 μ)

and (30 and above μ size) respectively. In treatment F3, the particales were segrgated 2.6, 2.6, 5.2, 39.47 and 50% in (1-2.5 μ), (2.6-5 μ), (5.1-10 μ), (10.1-30 μ) and (30 and above μ size) respectively. In treatment F4, the particales were segrgated 7.1, 0, 0, 28.57 and 64.28% in (1-2.5 μ), (2.6-5 μ), (5.1-10 μ), (10.1-30 μ) and (30 and above μ size) respectively. In treatment F5, the particales were segrgated 18.18, 9.09, 0, 27.27 and 45.45% in (1-2.5 μ), (2.6-5 μ), (5.1-10 μ), (10.1-30 μ) and (30 and above μ size) respectively. In treatment F6, the particales were segrgated 10, 0, 5. 20 and 65% in (1-2.5 μ), (2.6-5 μ), (5.1-10 μ), (10.1-30 μ) and (30 and above μ size) respectively. In treatment F7, the particales were segrgated 0, 9.09, 6.06, 23.33 and 70% in (1-2.5 μ), (2.6-5 μ), (5.1-10 μ), (10.1-30 μ) and (30 and above μ size) respectively. In treatment F8, the particales were segrgated 3.57, 3,57, 3,57, 14.28 and 75% in (1-2.5 μ), (2.6-5 μ), (5.1-10 μ), (10.1-30 μ) and (30 and above μ size) respectively. In treatment F9, the particales were segrgated 14.28, 0, 0 19.04 and 66.66% in (1-2.5 μ), (2.6-5 μ), (5.1-10 μ), (10.1-30 μ) and (30 and above μ size) respectively. Table 4.2 shows the average particle size (μ) of treatment combination (F1 to F9) flours.

Table 4.1: Particle size distribution of treatment combination (F1 to F9) flours in percentage

Treat ment s	No. of particles falling									
	0-2.5 microns		2.6-5.0 microns		5.1-10 microns		10.1-30 microns		30 microns and above	
	retain ed no.	%	retai ned no.	%	retain ed no.	%	retain ed no.	%	retai ned no.	%
F1	0	0.00	0	0.00	0	0.00	3	11.00	24	89.00
F2	3	7.60	1	2.50	2	5.10	13	33.33	20	51.28
F3	1	2.60	1	2.60	2	5.20	15	39.47	19	50.00
F4	1	7.10	0	0.00	0	0.00	4	28.57	9	64.28
F5	2	18.18	1	9.09	0	0.00	3	27.27	5	45.45
F6	2	10.00	0	0.00	1	5.00	4	20.00	13	65.00
F7	0	0.00	3	9.09	2	6.06	7	23.33	21	70.00
F8	1	3.57	1	3.57	1	3.57	4	14.28	21	75.00
F9	3	14.28	0	0.00	0	0.00	4	19.04	14	66.66

Table 4.2: Average particle size (μ) of treatment combination (F1 to F9) flours

Temperature	F1	F2	F3	F4	F5	F6	F7	F8	F9
60 ⁰ C	42.76	40.00	27.28	38.36	27.40	46.13	43.04	40.05	45.70

4.3 Physico-chemical properties of arrowroot, lesser yam and potato flours and their combinations (F1 to F9).

Physico-chemical properties include nutritional properties and functional properties of flours. Nutritional properties include protein, fat, fiber, ash, moisture and carbohydrates. The functional properties include bulk density, water absorption capacity, oil absorption capacity, flour dispersibility and yellowness index.

4.3.1 Nutritional properties of flour combinations (F1 to F9)

Nutritional properties (i.e. protein, fat, fibre ash and carbohydrate) of treatment composition of flours (F1 to F9) shown in Table 4.3. Table 4.4 shows the ANOVA for nutritional properties of flour combinations (F1 to F9).

4.3.1.1 Moisture content

The moisture content (MC) varied among treatment combination of flours from F1 to F9. Moisture content ranged between 5.81 ± 2.05 to $8.56 \pm 2.99\%$ (db). Treatment F2 displaying the highest MC ($8.56 \pm 2.99\%$ (db)) compared with treatment F1 which content low MC ($5.81 \pm 2.05\%$ (db)). The low moisture content of flours makes them easy to store at room temperature and less prone to fungal and microorganism infections making them amenable for utilization (Nuwamanya *et al.*, 2011). Moisture content is also an index of storage stability of the flour (Vengaiah *et al.*, 2013). Table 4.3 (a) shows the moisture content for treatment combination of flours. Table 4.4 (a) shows the ANOVA for change in moisture content at different treatment flour combinations from F1 to F9. The moisture content was significant at $p \leq 0.01$ for all treatments of flour combinations.

4.3.1.2 Protein content

Protein content varied from treatments F1 to F9. Protein content ranged between 2.27 ± 0.46 to $5.36 \pm 0.27\%$. Highest protein content observes in treatment F1 ($5.36 \pm 0.27\%$) as compare with treatment F3 ($2.27 \pm 0.46\%$) which content the lowest protein content in flour combinations. The proportion of lesser yam decreases from 0% to 50% and treatment F4 to F9 with increases protein content in treatment flour combinations. In general the process used in this study showed that the protein content for flours tested was higher than those that have been reported in literature i.e.: 0.5-2.0% (FW) for cassava flour, 1.0-3.0 %

(FW) for sweet potato flour and 2.0-4.0% (FW) for yam flour (Lebot, 2009). Table 4.3 (b) shows the protein content for treatment composition of flours. Table 4.4 (b) shows the ANOVA for change in protein at different flour combination treatments from F1 to F9. The increase in protein with decrease in lesser yam proportion in flour combination was significant at $p \leq 0.01$ for all types of flour combinations from F4 to F9.

Table 4.3: Nutritional Properties for treatment combination of flours (F1 to F9)

Constituents	F1	F2	F3	F4	F5	F6	F7	F8	F9
a. Moisture, % (db)	5.81± 2.05	8.56± 2.99	8.07±0 .65	6.89± 0.81	6.14± 0.29	7.84± 0.97	7.54± 0.59	6.15± 0.63	6.39± 0.65
b. Protein, %	5.36± 0.27	2.62± 0.35	2.27±0 .46	3.38± 0.10	3.20± 0.83	3.85± 0.18	4.02± 0.18	3.44± 0.10	4.25± 0.27
c. Fat, %	0.23± 0.03	0.61± 0.16	0.48±0 .02	0.98± 0.21	0.66± 0.13	0.70± 0.13	0.48± 0.03	0.53± 0.14	0.53± 0.06
d. Fiber, %	3.86± 0.04	1.08± 0.01	0.48±0 .05	1.39± 0.07	1.39± 0.03	1.42± 0.14	1.42± 0.14	1.36± 0.10	1.27± 0.02
e. Ash, %	4.14± 0.11	2.78± 0.18	3.92±0 .38	2.39± 0.43	1.91± 0.60	2.45± 0.23	2.51± 0.15	2.51± 0.11	2.93± 0.37
f. Carbohydrates, %	80.58± 2.11	84.33 ±3.24	84.75± 0.40	79.81 ±1.39	86.66 ±0.56	83.71 ±1.19	83.99 ±0.58	86.00 ±0.45	84.60 ±1.23

Table 4.4: ANOVA for Nutritional properties of flour combinations (F1 to F9)

Source of Variation	SS	Df	MS	F	P-value	F critical
a. Moisture content (% db)						
Flour Compositions	98.465	8	12.308	7.208	2.61E-04	2.510
Replications	30.733	18	1.707			
Total	129.198	26				
b. Protein (%)						
Flour Compositions	20.187	8	2.523	18.235	3.75E-07	2.510
Replications	2.490	18	0.138			
Total	22.678	26				
c. Fat (%)						
Flour Compositions	0.997	8	0.124	8.691	7.84E-05	2.510
Replications	0.258	18	0.014			
Total	1.256	26				
d. Fiber (%)						
Flour Compositions	20.719	8	2.589	331.103	6.28E-18	2.510
Replications	0.140	18	0.007			
Total	20.860	26				
e. Ash (%)						
Flour Compositions	12.898	8	1.612	15.003	1.65E-06	2.510

Replications	1.934	18	0.107			
Total	14.832	26				
f. Carbohydrate (%)						
Flour Compositions	79.797	8	9.974	4.865	0.002	2.510
Replications	36.904	18	2.050			
Total	116.701	26				

4.3.1.3 Fat content

Fat content varied from treatments F1 to F9. The fat content varied among different flour combinations. Fat content ranged between the 0.23 ± 0.03 to $0.98 \pm 0.21\%$. Highest fat content observes in treatment F4 ($0.98 \pm 0.21\%$) as compare with treatment F1 ($0.23 \pm 0.03\%$) has lowest amount of fat in flour combinations. The lesser yam proportion decreases in flour combinations from F4 to F9 with decreases in fat content of flour combinations. Fat content value is relatively low when compared to pigeon pea flour (1.8%) (Okpala and Mammah, 2001) and wheat flour (3.1%) (Akubor and Badifu, 2004) and similar results reported by Sankaralingam *et al.*, 1999. Similar observations reported in literature i.e.: 0.23% for arrowroot, 0.5% for potato and 0.5% for lesser yam (Wheatley *et al.*, 1995; Bradbury and Holloway, 1988) and 0.18% for cassava, 0.70% for sweet potato, 0.71 for potato (Odebunmi *et al.*, 2007). Table 4.3 (c) shows the fat content for treatment composition of flours. Table 4.4 (c) shows the ANOVA for change in fat content at different flour combination treatments from F1 to F9. The decrease in fat with decrease lesser yam proportion in flour combination was significant at $p \leq 0.01$ for treatment F4 to F9.

4.3.1.4 Fiber content

The fiber content varied among different flour combinations of flours from F1 to F9. Fiber content of flour composition ranged from 0.48 ± 0.05 to $3.86 \pm 0.04\%$. Highest fiber content observed in treatment F1 ($3.86 \pm 0.04\%$) compared with treatment F3 ($0.48 \pm 0.05\%$) which content lowest amount of fiber in flour composition. Lesser yam proportion decreases from F4 to F9 that increased fiber content in flour composition. This value is comparable to value of 3.1% reported by Sankaralingam *et al.*, (1999) for palmyrah. Similar observations reported in literature i.e. 4.4% for arrowroot, 0.5% for potato and 0.6% for yam, 1.0% for cassava, 1.0% for sweet potato (Wheatley *et al.*, 1995; Bradbury and Holloway, 1988) and 1.38% for cassava, 0.9% for sweet potato, 0.77 for potato (Odebunmi *et al.*, 2007). Fiber

content is range between 1.43 to 1.27%. Table 4.3 (d) shows the fiber content of treatment combinations of flours from F1 to F9. Table 4.4 (d) shows the ANOVA for change in fiber content at different flour combination treatments from F1 to F9. The increase in fiber with decrease lesser yam proportion in flour combination was significant at $p \leq 0.01$ for treatment F4 to F9.

4.3.1.5 Ash content

The ash content varied among different flour combinations of flours from F1 to F9. Ash content of flour composition ranged from 1.91 ± 0.60 to 4.14 ± 0.11 %. Highest ash content observed in treatment F1 ($4.14 \pm 0.11\%$) compared with treatment F3 ($1.91 \pm 0.60\%$) which content lowest amount of ash in flour composition. Lesser yam proportion decreases from treatment F4 to F9 with increases ash content in flour composition. Ash content of 2.8 to 3.3% (dry matter basis) has been reported for palmyrah tubers (Sankaralingam *et al.*, 1999). The disparity may be due to varietal differences and the locality. Similar observations reported in literature i.e. 1.0-1.5% for potato and 0.5-1.0% for yam, 0.5-1.5% for cassava, 1.0% for sweet potato (Wheatley *et al.*, 1995; Bradbury and Holloway, 1988) and 0.85% for cassava, 0.97% for sweet potato, 1.45% for potato (Odebunmi *et al.*, 2007). Table 4.3 (e) shows the ash content of treatment combinations of flours from F1 to F9. Table 4.4 (e) shows the ANOVA for change in ash content at different flour combination treatments from F1 to F9. The increase in ash content with decrease lesser yam proportion in flour combination was significant at $p \leq 0.01$ for treatment F4 to F9.

4.3.1.6 Carbohydrates

The carbohydrate content varied among different flour combinations of flours. Carbohydrate content of flour composition ranged from 79.81 ± 1.39 to $86.66 \pm 0.56\%$. Highest carbohydrate content observed in treatment F5 ($86.66 \pm 0.56\%$) compared with treatment F4 ($79.81 \pm 1.39\%$) which content lowest amount of carbohydrate in flour composition. Table 4.3 (f) shows the carbohydrate content of treatment combinations of flours from F1 to F9. Table 4.4 (f) shows the ANOVA for change in carbohydrates content at different flour combination treatments from F1 to F9. The increase in carbohydrates with decrease lesser yam proportion in flour combination was significant at $p \leq 0.01$ for treatment F4 to F9.

4.3.2 Functional Properties of treatment composition of flours (F1 to F9)

Functional properties (i.e. water absorption capacity, oil absorption capacity, bulk density, flour dispersibility and colour) of treatment composition of flours (F1 to F9) were shown in Table 4.5.

4.3.2.1 Water absorption capacity (WAC)

Water absorption capacity describes flour-water association ability under limited water supply. Water absorption capacity ranged from 1.36 ± 0.06 to 2.46 ± 0.25 ml/g. Highest water absorption capacity observed in treatment F3 (2.46 ± 0.25 /g) compared with treatment F1 (1.36 ± 0.06 ml/g) which was lowest value in flour composition. The water absorption capacity for the palmyrah tuber flour was 18% (2.5 ml/g), 1.7 ml/g reported for African yam bean, 3 to 4 ml/g for tiger nut flour, 0.22- 0.64ml/g was for the elephant foot yam starches (Sankaralingam *et al.*, 1999; Eke and Akobundu, 1993; Oladele and Aina, 2007; Babu and Parimalavalli, 2012). The water absorption capacity (WAC) increased from treatment F4 (2.10 ± 0.20 ml/g) to F6 (2.16 ± 0.25 ml/g) and further decreased for F7 (1.90 ± 0.10 ml/g) and increased from F8 (2.06 ± 0.20 ml/g) to F9 (1.86 ± 0.15 ml/g) as the percentage of lesser yam decreased in flour formulation from treatments F4 to F9. The result obtained shows that the flours used i.e. treatments F1 to F9 has a good ability to bind water. Table 4.5 (a) shows the water absorption capacity (WAC) of treatment combination of flours. Table 4.6 (a) shows the ANOVA for the water absorption capacity of different flour combination treatments from F1 to F9. The decrease in water absorption capacity with respect to the decrease lesser yam flour composition in treatments from F4 to F9 was significant at $p \leq 0.01$.

4.3.2.2 Oil absorption capacity (OAC)

Oil absorption capacity ranged from 0.63 ± 0.25 to 1.56 ± 0.05 ml/g. Highest oil absorption capacity observed in treatment F4 and F6 (1.56 ± 0.05 ml/g) compared with treatment F3 (0.63 ± 0.25 ml/g) which has lowest value. The values of oil absorption capacities for palmyrah tuber was found to be 14% (1.7ml/g), 1.0 to 1.1ml/g for tiger nut flour, 1.2 to 1.4ml/g for raw winged bean, 1.06-1.40ml/g for cush-cush yam starches (Sankaralingam *et al.*, 1999; Oladele and Aina, 2007; Narayana and Rao, 1982; Eke and Akobundu, 1993 and Babu and Parimalavalli, 2012). As increase in arrowroot composition retains the oil absorption capacity. The oil absorption capacity decreased as lesser yam proportion decreased in flour combination from F4 to F9. Oil absorption is an important property in food formulations because fats improve the flavor retention and mouth feel of foods (Kinsella, 1976). The result obtained shows that arrowroot tuber flour is a high flavour retainer and may therefore find useful application in food systems and formulation. Table 4.5 (b) shows the oil absorption capacity (OAC) of treatment combination of flours. Table 4.6 (b) shows the ANOVA for the oil absorption capacity of different flour combination treatments from F1 to

F9. The decrease in oil absorption capacity with respect to the decrease lesser yam flour composition in treatments from F4 to F9 was significant at $p \leq 0.01$.

4.3.2.3 Bulk density (BD)

Bulk density ranged from 2.41 ± 0.00 to 4.31 ± 0.25 g/cm³. Highest bulk density observed in treatment F2 (4.31 ± 0.25 g/cm³) and lowest bulk density was observed in treatment F1 (2.41 ± 0.00 g/cm³). Bulk density depends upon the particle size of the samples. Bulk density is a measure of heaviness of a flour sample. The value of bulk density for palmyrah tuber was 0.7 g/cm³, 0.6 g/cm³ for tiger nut flour, 0.5 g/cm³ for African breadfruit

Table 4.5: Functional Properties for treatment combination of flours (F1 to F9)

Constituents	F1	F2	F3	F4	F5	F6	F7	F8	F9
a. Water absorbtion capacity, ml/g	1.36 ± 0.06	2.00 ± 0.10	2.46 ± 0.25	2.10 ± 0.20	2.20 ± 0.10	2.16 ± 0.25	1.90 ± 0.10	2.06 ± 0.20	1.86 ± 0.15
b. Oil absorbtion capacity, ml/g	1.26 ± 0.25	0.90 ± 0.10	0.63 ± 0.25	1.56 ± 0.05	1.30 ± 0.10	1.56 ± 0.05	1.40 ± 0.20	1.33 ± 0.05	1.13 ± 0.15
c. Bulk density, g/cm³	2.41 ± 0.00	4.31 ± 0.25	4.07 ± 0.25	3.92 ± 0.39	3.88 ± 0.48	3.65 ± 0.33	3.87 ± 0.21	3.87 ± 0.21	3.92 ± 0.55
d. Flour dispersibility, %	34.33 ± 0.58	24.33 ± 2.08	41.66 ± 0.57	39.33 ± 1.15	38.66 ± 1.15	39.33 ± 1.15	49.33 ± 2.30	41.00 ± 1.00	40.00 ± 2.00
e. Yellowness Index	21.81 ± 0.14	27.99 ± 0.77	32.16 ± 2.16	29.04 ± 0.97	27.29 ± 0.51	26.34 ± 0.79	25.90 ± 0.35	25.19 ± 0.28	23.97 ± 0.08

Table 4.6: ANOVA for Functional properties of flour combinations (F1 to F9)

Source of Variation	SS	df	MS	F	P-value	F critical
a. Water absorption capacity (ml/g)						
Flour compositions	2.180	8	0.272	9.2	5.37E-05	2.510
Replications	0.533	18	0.029			
Total	2.714	26				
b. Oil absorption capacity (ml/g)						
Flour compositions	2.24	8	0.280	11.454	1.18E-05	2.510
Replications	0.44	18	0.024			
Total	2.68	26				
c. Bulk density (g/cm³)						
Flour compositions	6.988	8	0.873	7.599	1.87E-04	2.510
Replications	2.069	18	0.114			
Total	9.057	26				
d. Flour dispersibility (%)						
Flour compositions	1075.333	8	134.416	68.476	6.73E-12	2.510
Replications	35.333	18	1.962			
Total	1110.667	26				
e. Yellowness Index						
Flour compositions	220.205	8	27.525	31.419	4.85E-09	2.510

Replications	15.769	18	0.876			
Total	235.974	26				

kernel flour, 0.7 g/cm³ for wheat flour (Sankaralingam *et al.*, 1999; Oladele and Aina, 2007; Akubor and Badifu, 2004). It is important for determining packaging requirements, material handling and application in wet processing in the food industry. Since flours with high bulk densities are used as thickeners in food products, the lesser yam tuber flour studied could be used as a thickener. Table 4.5 (c) shows the bulk density (BD) of treatment combination of flours. Table 4.6 (c) shows the ANOVA for the bulk density of different flour combination treatments from F1 to F9. The bulk density decreased from F4 (3.92±0.39g/cm³) to F6 (3.65±0.33g/cm³) further increased from F7 (3.87±0.21g/cm³) to F9 (3.92±0.55g/cm³) as lesser yam proportion decreased from F4 to F9 was significant at p≤0.01.

4.3.2.4 Flour dispersibility (FD)

Flour dispersibility ranged from 24.33±2.08-41.33±2.30%. Highest flour dispersibility observed in treatment F7 (41.33±2.30%) and lowest value of flour dispersibility was observed in treatment F2 (24.33±2.08%). The flour dispersibility increased from F4 (39.33±1.15%) to F7 (49.30±2.30%) further decreased from F8 (41.00±1.00%) to F9 (40.00±2.00%) as lesser yam proportion decreased from F4 to F9. Table 4.5 (d) shows the flour dispersibility of treatment combination of flours. Table 4.6 (d) shows the ANOVA for the flour dispersibility of different flour combination treatments from F1 to F9. The increase in flour dispersibility with respect to the decrease lesser yam flour composition in treatments from F4 to F9 was significant at p≤0.01.

4.3.2.5 Yellowness Index (YI)

Yellowness index ranges from 21.81±0.14 to 32.16±2.16. Highest yellowness index observed in treatment F3 (32.16±2.16) and lowest value of flour dispersibility was observed in treatment F1 (21.81±0.14). Table 4.5 (e) shows the yellowness index of treatment combination of flours. Table 4.6 (e) shows the ANOVA for the yellowness index of different flour combination treatments from F1 to F9. The decrease in yellowness index with respect to the decrease lesser yam flour composition in treatments from F4 to F9 was significant at p≤0.01.

4.4 Influence of flour compositions and extrusion parameters on functional and nutritional properties of extrudates.

The functional properties of extrudates include expansion ratio, hardness, water absorption index, water solubility index and bulk density. The nutritional properties of extrudates include the protein, fat, fiber, ash, moisture content, carbohydrates and yellowness index. Figures 4.5, 4.6 and 4.7 shows the extruded samples prepared at varied temperature of 130, 150 and 170°C respectively.

4.4.1 Functional properties of extrudates

Effect of flour combinations and extrusion parameters on functional properties of extrudates i.e. expansion ratio, bulk density, hardness, water solubility index and water absorption index are discussed below.



T1 (0:50:50); 330 rpm



T1 (0:50:50); 360 rpm



T1 (0:50:50); 390 rpm



T2 (10:40:50); 330 rpm



T2 (10:40:50); 360 rpm



T2 (10:40:50); 390 rpm



T3 (20:30:50); 330 rpm



T3 (20:30:50); 360 rpm



T3 (20:30:50); 390 rpm



T4 (30:20:50); 330 rpm



T4 (30:20:50); 360 rpm



T4 (30:20:50); 390 rpm



T5 (40:10:50); 330 rpm



T5 (40:10:50); 360 rpm



T5 (40:10:50); 390 rpm



T6 (50:0:50); 330 rpm



T6 (50:0:50); 360 rpm



T6 (50:0:50); 390 rpm

Fig. 4.5: Extrudates samples at temperature 130°C



T1 (0:50:50); 330 rpm



T1 (0:50:50); 360 rpm



T1 (0:50:50); 390 rpm



T2 (10:40:50); 330 rpm



T2 (10:40:50); 360 rpm



T2 (10:40:50); 390 rpm



T3 (20:30:50); 330 rpm



T3 (20:30:50); 360 rpm



T3 (20:30:50); 390 rpm



T4 (30:20:50); 330 rpm



T4 (30:20:50); 360 rpm



T4 (30:20:50); 390rpm



T5 (40:10:50); 330 rpm



T5 (40:10:50); 360 rpm



T5 (40:10:50); 390 rpm



T6 (50:0:50); 330 rpm



T6 (50:0:50); 360 rpm



T6 (50:0:50); 390 rpm

Fig. 4.6: Extrudates samples at temperature 150°C



T1 (0:50:50); 330 rpm



T1 (0:50:50); 360 rpm



T1 (0:50:50); 390 rpm



T2 (10:40:50); 330 rpm



T2 (10:40:50); 360 rpm



T2 (10:40:50); 390 rpm



T3 (20:30:50); 330 rpm



T3 (20:30:50); 360 rpm



T3 (20:30:50); 390 rpm



T4 (30:20:50); 330 rpm



T4 (30:20:50); 360 rpm



T4 (30:20:50); 390 rpm



T5 (40:10:50); 330 rpm



T5 (40:10:50); 360 rpm



T5 (40:10:50); 390 rpm



Fig. 4.7: Extrudates samples at temperature 170°C

4.4.1.1 Expansion ratio (ER)

The expansion ratio for tuber crops extrudates were in the range of 2.12-3.35 for all the treatments (T1 to T6), temperature of extrusion (130 to 170°C) and screw speed (330 to 390). Expansion ratio for treatment T1 ranges from 2.45-3.35, for T2 from 2.55-3.18, for T3 from 2.38-3.06, for T4 from 2.19-3.01, for T5 from 1.96-2.99 and for T6 from 2.12-3.06 respectively. Fig. 4.8 (a)-(f) shows the surface plots of effect of temperature of extrusion (°C) and screw speed (rpm) on the expansion ratio of the extrudates for treatment (a) T1, (b) T2, (c) T3, (d) T4, (e) T5, (f) T6. As the temperature of extrusion increases from 130°C to 170°C, the expansion ratio of extrudates increases for all treatments i.e. T2 to T6. However in treatment T1 the expansion ratio increases gradually from 130°C to 145°C followed by decreasing trend up to 170°C, which can be observed from contour plots Fig. 4.9 (a)-(f). Similarly if the screw speed of the extruder increases from 330 rpm to 390 rpm the expansion ratio increases for treatments T1, T2, T3, T4, T5 and T6. In treatment T5 as the screw speed increases from 330 rpm to 390 rpm the expansion ratio increases up to 360 rpm followed by a decreasing trend.

During the extrusion cooking lesser yam flour play significant role in expansion of extrudates. In extrusion cooking, if lesser yam proportion increases in flour combination then the expansion ratio of extrudates also increases and vice versa. In treatments T1, T2, T3, T4, T5 and T6 expansion ratio decreases with decrease the proportion of lesser yam in flour combination from T1 to T6 during extrusion cooking which is shown in Table 4.7.

The second order polynomials equation shows the effect of temperature of extrusion (°C) and screw speed (rpm) on the expansion ratio of tuber crop extrudates for treatments T1, T2, T3, T4, T5 and T6 are given in Eq.. (4.1), (4.2), (4.3), (4.4), (4.5) and (4.6) respectively.

$$ER_{T1} = -24.826 + 0.047S - 7.611 \times 10^{-5}S^2 + 0.255T + 7.708 \times 10^{-5}ST - 9.587 \times 10^{-4}T^2 \quad (r^2 = 0.998)$$

...(4.1)

$$ER_{T2} = -29.858 + 0.093S - 9.648 \times 10^{-5}S^2 + 0.198T - 1.299 \times 10^{-5}ST - 4.920 \times 10^{-4}T^2 \quad (r^2 = 0.999)$$

...(4.2)

$$ER_{T3} = -8.717 + 7.129 \times 10^{-3}S + 1.203 \times 10^{-5}S^2 + 0.120T - 8.208 \times 10^{-5}ST - 2.70 \times 10^{-4}T^2 \quad (r^2 = 0.999)$$

...(4.3)

$$ER_{T4} = 2.197 - 0.012S + 6.685 \times 10^{-5}S^2 + 0.016T - 2.258 \times 10^{-4}ST + 2.541 \times 10^{-4}T^2 \quad (r^2 = 0.997)$$

...(4.4)

$$ER_{T5} = 12.922 + 0.075S - 9.074 \times 10^{-5}S^2 + 0.011T - 8.125 \times 10^{-5}ST + 1.233 \times 10^{-4}T^2 \quad (r^2 = 0.998)$$

...(4.5)

$$ER_{T6} = -10.283 + 0.063S - 4.611 \times 10^{-5}S^2 + 6.783 \times 10^{-3}T - 2.075 \times 10^{-4}ST + 2.78710^{-4}T^2 \quad (r^2 = 0.999)$$

...(4.6)

Where;

T=Temperature of barrel (extrusion) °C

S= Screw speed (rpm)

ER_{T1}, ER_{T2}, ER_{T3}, ER_{T4}, ER_{T5} and ER_{T6} = Expansion ratio at treatment T1, T2, T3, T4, T5 and T6 respectively.

Table 4.7 and 4.8 (a) shows the ANOVA for the effect of flour composition (T1-T6), temperature of extrusion (130-170°C) and screw speed (330-390 rpm) on expansion ratio of the tuber crops extrudates at $p \leq 0.01$. It is clear from the table, all the quadratic effects from barrel temperature, screw speed and ingredient composition were significant with ER. The interaction effect between barrel temperature and screw speed, screw speed, ingredient composition and barrel temperature were significant ($p \leq 0.01$) with ER. In expansion ratio, individual effect of screw speed and temperature were significant effect on the ingredients composition. The effect of temperature at constant screw speed along with flour composition on expansion ratio was a non significant ($p \leq 0.01$).

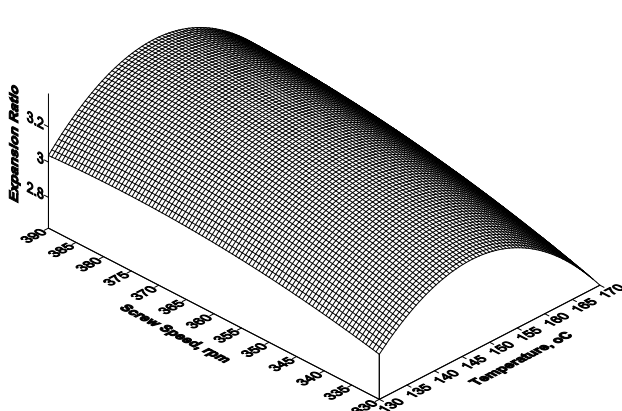
The combined effect of increase of barrel temperature (130-170°C) and increase of screw speed (330-390 rpm) increases the expansion ratio for all the treatments i.e. T1 to T6. Increase in barrel temperature with increase in screw speed increased the expansion ratio of extrudates. Similar observations observed in barley grape pomace, carrot rice pulse, carrot pomace powder, broken rice flour:pineapple waste pulp powder: red gram powder, wheat:mungbean:groundnut (Kumar *et al.*, 2010; Altan *et al.*, 2008; Upadhyay, 2009; Ding *et al.*, 2006; Pathania *et al.*, 2013; Kothakota *et al.*, 2013) have been reported.

The expansion ratio increased with increases in screw speed, which may be due to high mechanical shear resulting in higher expansion. The expansion ratio rapidly increased with increase in temperature which may be due to higher degree of superheating of water in

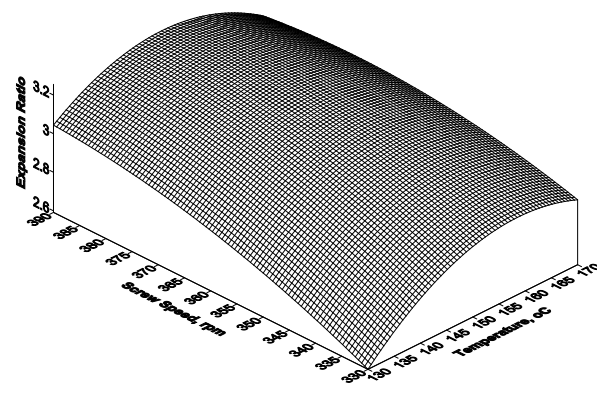
the extruder encountering the bubble formation consequently resulting in higher expansion (Ding *et al.*, 2006).

4.4.1.2 Bulk density (BD)

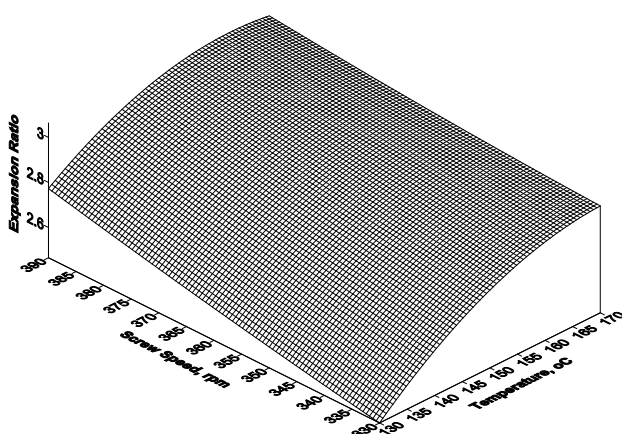
Fig. 4.10 (a)-(f) shows the surface plots of effect of temperature of extrusion ($^{\circ}\text{C}$) and screw speed (rpm) on the bulk density of extrudates for treatment (a) T1, (b) T2, (c) T3, (d) T4, (e) T5 and (f) T6. The bulk density for tuber crops extrudates were in the range of $0.123\text{--}0.553\text{g/cm}^3$ for treatments (T1 to T6), temperature of extrusion (130 to 170°C) and screw speed (330 to 390 rpm). Bulk density for treatment T1 ranges from $0.122\text{--}0.279\text{g/cm}^3$, for T2 from $0.134\text{--}0.315\text{g/cm}^3$, for T3 from $0.123\text{--}0.351\text{g/cm}^3$, for T4 from $0.127\text{--}0.380\text{g/cm}^3$, for T5 from $0.198\text{--}0.459\text{g/cm}^3$ and for T6 from $0.148\text{--}0.553\text{g/cm}^3$ respectively for all treatments (T1 to T6), temperature of extrusion (130 to 170°C) and screw speed (330 to 390 rpm). As the extrusion temperature increases from 130°C to 170°C the bulk density of the extrudates decreases for treatments T2 to T6.



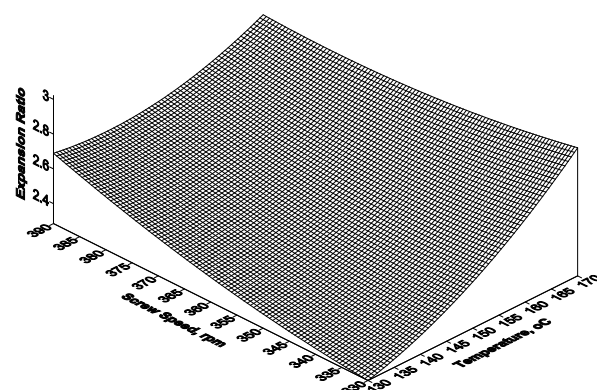
(a)T1



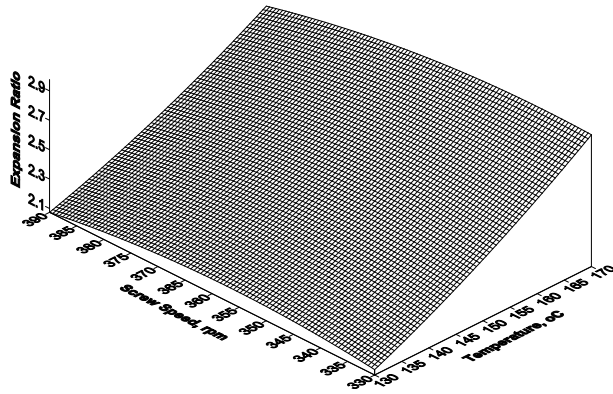
(b)T2



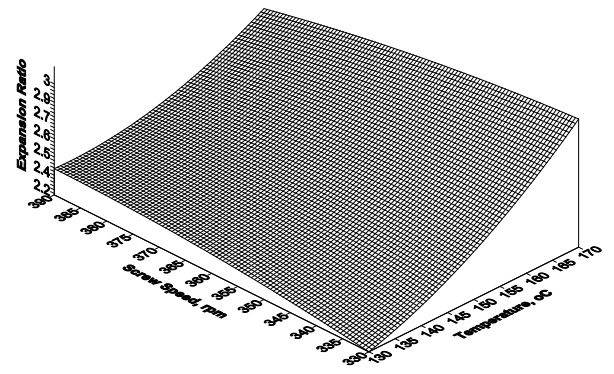
(c)T3



(d)T4

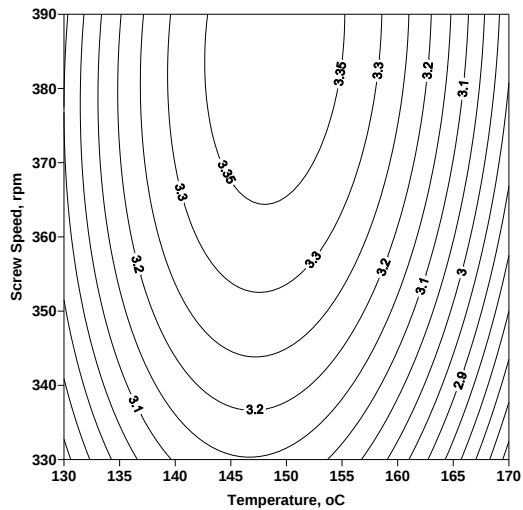


(e)T5

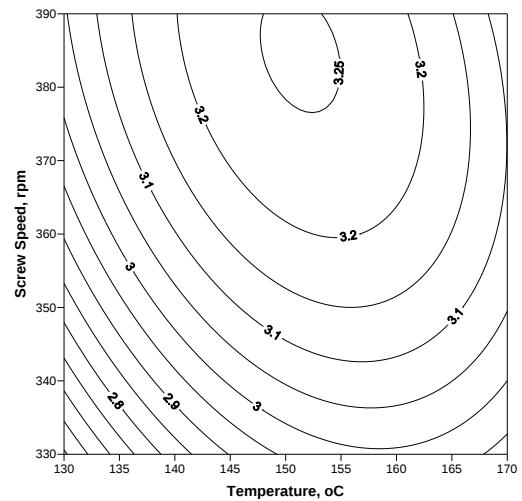


(f)T6

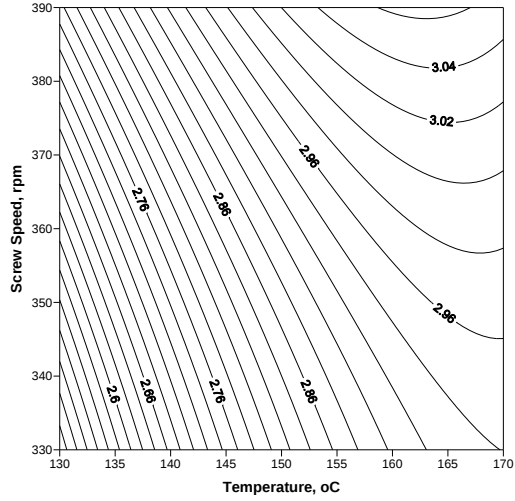
Fig. 4.8: Surface plots of Effect of Temperature of Extrusion, Screw Speed on Expansion Ratio of Tuber Crops based extrudates (a) For Treatment T1; (b) For Treatment T2; (c) For T For Treatment T3; (d) For Treatment T4; (e) For Treatment T5; (f)For Treatment T6.



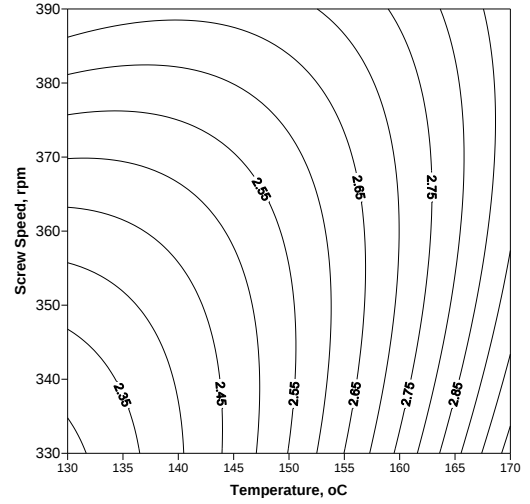
(a)T1



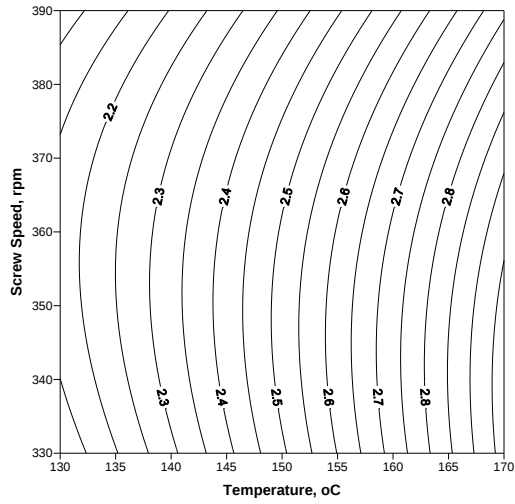
(b)T2



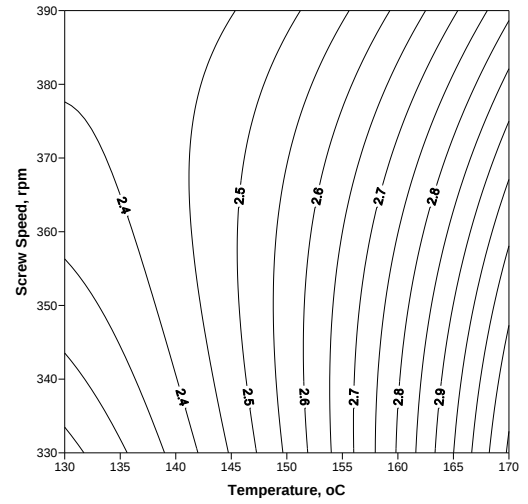
(c)T3



(d)T4



(e)T5



(f)T6

Fig. 4.9: Contour plots of Effect of Temperature of Extrusion, Screw Speed on Expansion ratio of Tuber Crops based Extrudates (a) For Treatment T1; (b) For Treatment T2; (c) For T For Treatment T3; (d) For Treatment T4; (e) For Treatment T5; (f) For Treatment T6.

Table 4.7: Effect of flour composition, temperature of extrusion and the screw speed on the expansion ratio of the Tuber crops

extrudates.

Treatments	Flour composition (Arrowroot: Lesser Yam: Potato)	130°C			150°C			170°C		
		330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm
T1	0:50:50	2.830 ^a	3.005 ^a	3.111 ^a	3.356 ^a	3.140 ^a	3.356 ^a	2.457 ^b	3.077 ^a	2.923 ^b
T2	10:40:50	2.552 ^b	2.929 ^a	3.060 ^a	3.004 ^b	3.209 ^a	3.189 ^a	2.921 ^{ba}	3.044 ^a	3.117 ^a
T3	20:30:50	2.380 ^c	2.688 ^b	2.779 ^c	2.975 ^b	2.760 ^b	3.001 ^b	2.862 ^{ba}	3.050 ^a	3.064 ^a
T4	30:20:50	2.333 ^c	2.190 ^d	2.880 ^b	2.635 ^c	2.678 ^c	2.484 ^c	2.892 ^{ba}	3.012 ^a	2.897 ^b
T5	40:10:50	2.247 ^{cd}	1.967 ^e	2.144 ^e	2.348 ^d	2.659 ^{cb}	2.347 ^{dc}	2.977 ^a	2.990 ^a	2.679 ^c
T6	50:0:50	2.127 ^d	2.404 ^c	2.471 ^d	2.708 ^c	2.593 ^c	2.309 ^d	3.061 ^a	2.919 ^a	2.907 ^b
SE₁		0.0325	0.0230	0.0181	0.0281	0.0310	0.03796	0.1063	0.0674	0.0261
CD₁ at 1%		0.1456	0.1030	0.0811	0.1259	3.1693	0.1702	0.4766	0.3023	0.1172
SE₂		0.0119								
CD₂ at 1%		0.0441								
SE₃		0.0503								
CD₃ at 1%		0.1395								

((‘a’-‘a’, ‘b’-‘b’, ‘c’-‘c’, ‘d’-‘d’, ‘e’-‘e’, ‘ba’-‘ba’, ‘bc’-‘bc’ are non significant at ($p \leq 0.01$); ‘a’-‘b’, ‘b’-‘c’, ‘c’-‘d’, ‘b’-‘ba’, ‘a’-‘ba’, ‘c’-‘ba’ are significant at ($p \leq 0.01$)). (SE₁ and CD₁ = Effect of treatment combination, individual temperature and screw speed on expansion ratio. SE₂ and CD₂ = Effect of temperature and treatment combination on expansion ratio. SE₃ and CD₃ = Effect of treatment combination, temperature and screw speed on expansion ratio.)).

Table 4.8: ANOVA for Functional Properties of extrudates

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F_{crit}</i>
a. Expansion ratio						
Treatments	2.190444	5	0.43809	8.62631	1.30E-05	2.44947
Processing conditions	1.745	8	0.21813	4.29505	0.00085	2.18017
Error	2.031408	40	0.05079			
Total	5.966852	53				
b. Bulk density (g/cm³)						
Treatments	0.113485	5	0.0227	8.71237	1.18E-05	2.44947
Processing conditions	0.210924	8	0.02637	10.1205	1.39E-07	2.18017
Error	0.104206	40	0.00261			
Total	0.428615	53				
c. WAI (g/g)						
Treatments	2.451859	5	0.49037	1.3858	0.2502	2.44947
Processing conditions	6.225793	8	0.77822	2.19927	0.04814	2.18017
Error	14.15421	40	0.35386			
Total	22.83186	53				
d. WSI (%)						
Treatments	1697.44	5	339.488	132.492	8.71E-24	2.44947
Processing conditions	228.7105	8	28.5888	11.1573	4.03E-08	2.18017
Error	102.4934	40	2.56233			
Total	2028.643	53				
e. Hardness (g)						
Treatments	1.93E+08	5	3.9E+07	6.50697	0.00016	2.44947
Processing conditions	2.92E+08	8	3.6E+07	6.15081	3.61E-05	2.18017
Error	2.37E+08	40	5924891			
Total	7.21E+08	53				

However in treatment T1 the bulk density decreases gradually from 130°C to 150°C followed by increasing trend up to 170°C which can be observed from contour plots Fig. 4.11 (a)-(f). Similarly as the screw speed of the extruder increases from 330 to 390 rpm bulk density decreases for treatments T1, T2, T3, T4 and T6. In treatment T5 as the screw speed increases from 330 to 390 rpm the bulk density decreases up to 350 rpm followed by increasing trend up to 90 rpm.

During extrusion cooking, lesser yam plays a significant role in bulk density of the extruded products. As the composition of lesser yam increases in flour composition, bulk

density of extrudates decreased and vice versa. For treatment T1 to T6 proportion of lesser yam decreased from 50% to 00% and bulk density of extrudates also increased shown in Table 4.8.

The second order polynomials equation shows the effect of temperature of extrusion (°C) and screw speed (rpm) on the bulk density of tuber crop extrudates for treatments T1, T2, T3, T4, T5 and T6 are given in Eq. (4.7), (4.8), (4.9), (4.10), (4.11) and (4.12) respectively.

$$BD_{T1} = 7.473 - 0.016S + 1.185 \times 10^{-5}S^2 - 0.055T + 5.166 \times 10^{-5}ST + 1.2 \times 10^{-4}T^2 \quad (r^2 = 0.983) \quad \dots(4.7)$$

$$BD_{T2} = 9.005 - 0.033S + 2.981 \times 10^{-5}S^2 - 0.034T + 6.791 \times 10^{-5}ST + 2.958 \times 10^{-5}T^2 \quad (r^2 = 0.981) \quad \dots(4.8)$$

$$BD_{T3} = 13.447 - 0.048S + 5.351 \times 10^{-5}S^2 - 0.055T + 5.874 \times 10^{-5}ST + 1.091 \times 10^{-4}T^2 \quad (r^2 = 0.988) \quad \dots(4.9)$$

$$BD_{T4} = 8.542 - 0.029S + 1.685 \times 10^{-5}S^2 - 0.033T + 1.091 \times 10^{-4}ST - 2.708 \times 10^{-5}T^2 \quad (r^2 = 0.990) \quad \dots(4.10)$$

$$BD_{T5} = 14.714 - 0.063S + 8.592 \times 10^{-5}S^2 - 0.036T + 7.083 \times 10^{-6}ST + 9.708 \times 10^{-5}T^2 \quad (r^2 = 0.994) \quad \dots(4.11)$$

$$BD_{T6} = 18.764 - 0.076S + 8.018 \times 10^{-5}S^2 - 0.055T + 1.216 \times 10^{-4}ST + 2.041 \times 10^{-5}T^2 \quad (r^2 = 0.983) \quad \dots(4.12)$$

Where;

T=Temperature of barrel (extrusion) °C

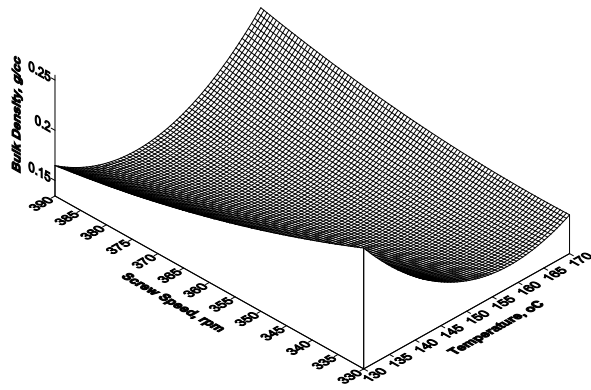
S= Screw speed (rpm)

BD_{T1}, BD_{T2}, BD_{T3}, BD_{T4}, BD_{T5} and BD_{T6} = Bulk density at treatment T1, T2, T3, T4, T5 and T6 respectively.

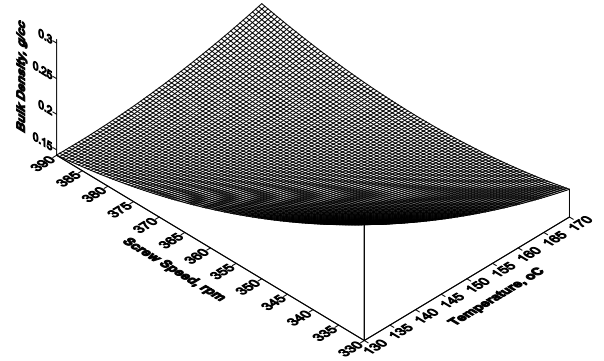
Table 4.9 and 4.8 (b) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the bulk density of the tuber crops extrudates. It is clear from the table, flour composition, screw speed and temperature have a significant effect ($p \leq 0.01$) on bulk density. The interaction between the flour compositions, screw speed and temperature has also a significant difference ($p \leq 0.01$) on the bulk density.

The trend of bulk density was inversely related to the expansion ratio. Decrease in bulk density with increase in temperature, which may be due to increasing the pressure inside the extruder barrel. Decrease in bulk density with increases in screw speed, which may due to the starch gelatinization decreases (Hagenimana *et al.*, 2006).

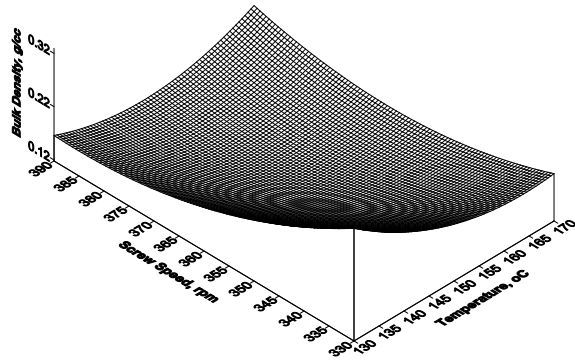
The combined effect of increase in barrel temperature (130-170°C) and screw speed (330-390 rpm) decreases the bulk density for all the treatments i.e. T1 to T6 of tuber crops extrudates. Increase in barrel temperature with increase in screw speed decreases bulk density



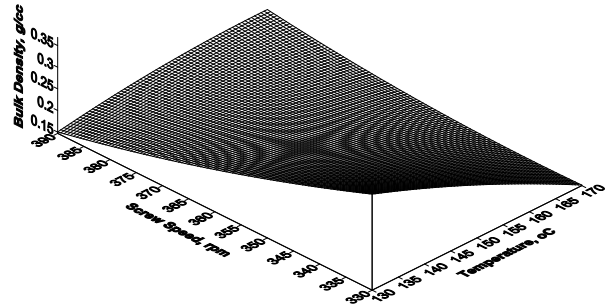
(a)T1



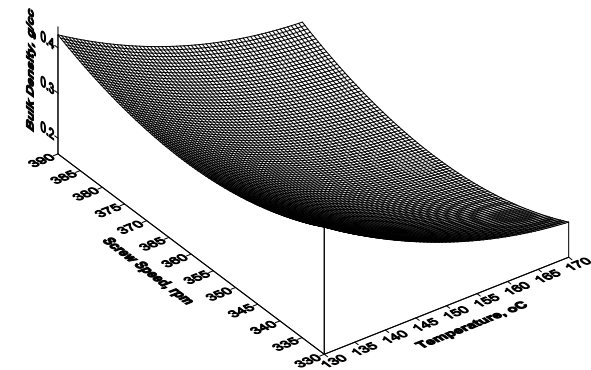
(b)T2



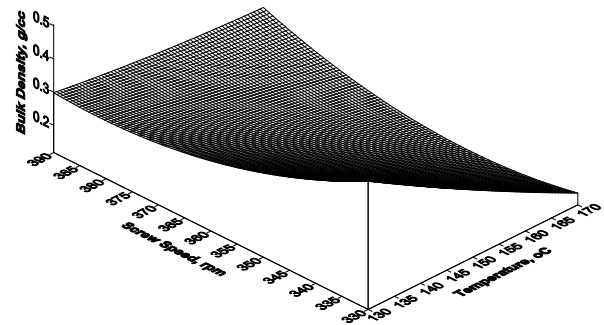
(c)T3



(d)T4

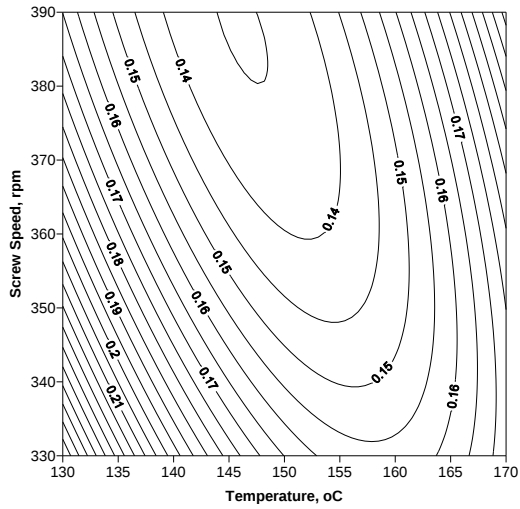


(e)T5

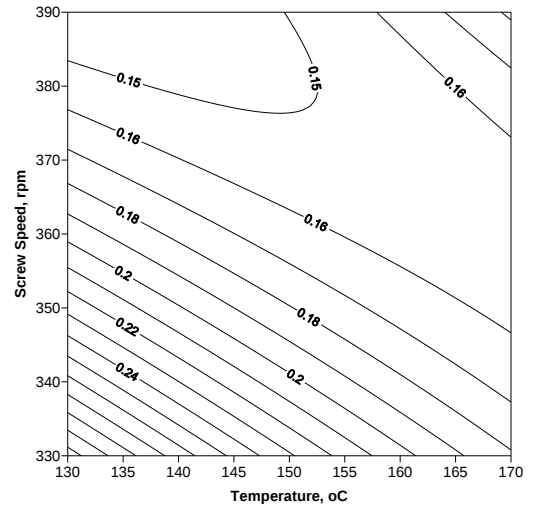


(f)T6

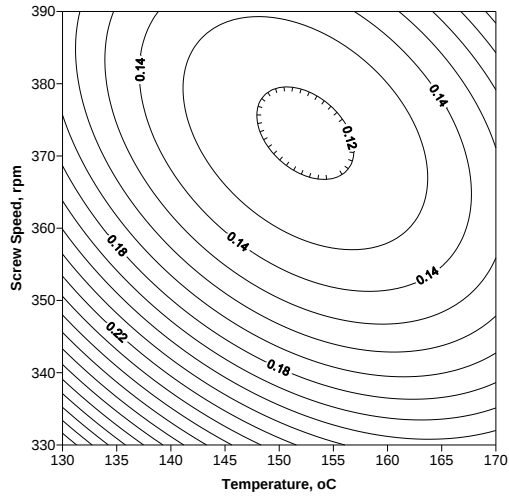
Fig. 4.10: Surface plots of Effect of Temperature of Extrusion, Screw Speed on Bulk Density (a) For Treatment T1; (b) For Treatment T2; (c) For T For Treatment T3; (d) For Treatment T4; (e) For Treatment T5; (f) For Treatment T6



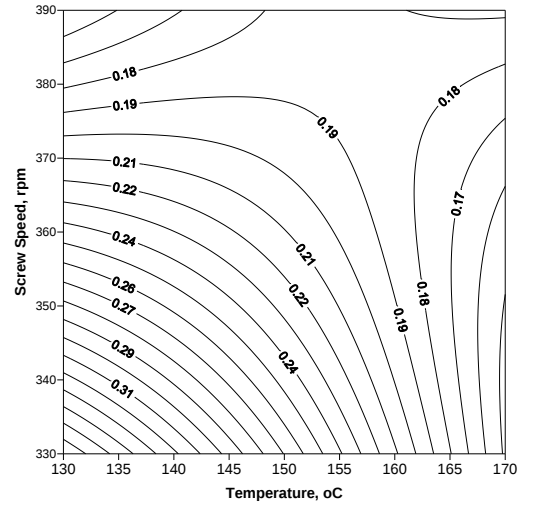
(a)T1



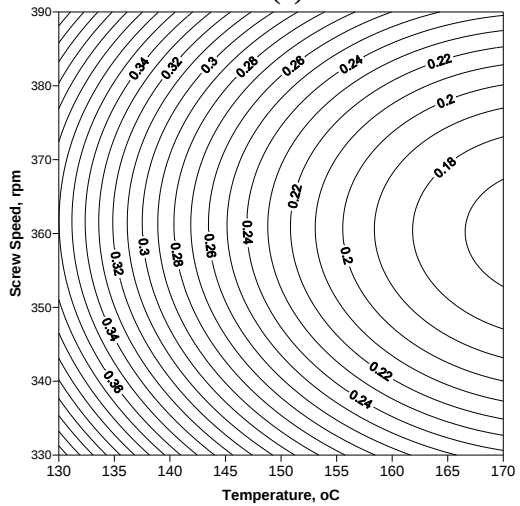
(b)T2



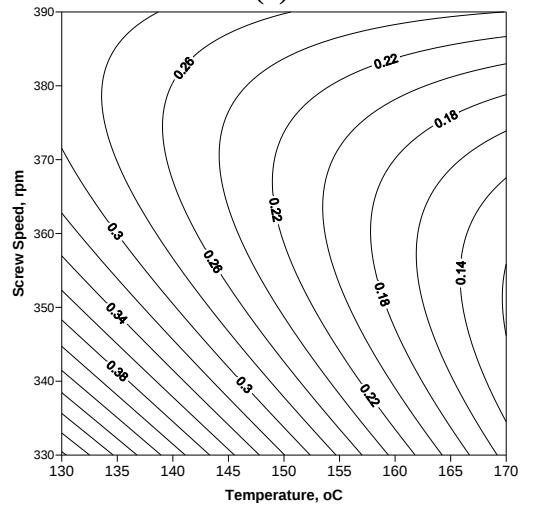
(c)T3



(d)T4



(e)T5



(f)T6

Fig. 4.11: Contour plots of Effect of Temperature of Extrusion, Screw Speed on Bulk Density of Tuber Crops based Extrudates (a) For Treatment T1; (b) For Treatment T2; (c) For T For Treatment T3; (d) For Treatment T4; (e) For Treatment T5; (f) For Treatment T6.

Table 4.9: Effect of flour composition, temperature of extrusion and the screw speed on the Bulk Density (g/cm^3) of the Tuber crops

extrudates.

Treatments	Flour composition (Arrowroot: Lesser Yam: Potato)	130°C			150°C			170°C		
		330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm
T1	0:50:50	0.279 ^c	0.174 ^b	0.166 ^c	0.122 ^c	0.180 ^a	0.140 ^b	0.192 ^{ba}	0.165 ^a	0.203 ^{ba}
T2	10:40:50	0.315 ^c	0.158 ^b	0.172^c	0.254 ^{ba}	0.158 ^a	0.134 ^b	0.149 ^{ba}	0.200 ^a	0.169 ^b
T3	20:30:50	0.351 ^{bc}	0.168 ^b	0.176 ^c	0.193 ^b	0.170 ^a	0.123 ^b	0.217 ^{ba}	0.139 ^a	0.183 ^{ba}
T4	30:20:50	0.380 ^{bc}	0.205 ^{ba}	0.179 ^c	0.280 ^a	0.225 ^a	0.157 ^b	0.127 ^b	0.180 ^a	0.188 ^{ba}
T5	40:10:50	0.459 ^{ba}	0.318 ^a	0.459 ^a	0.319 ^a	0.234 ^a	0.274 ^a	0.218 ^a	0.198 ^a	0.235 ^a
T6	50:0:50	0.553 ^a	0.287 ^{ba}	0.291 ^b	0.255 ^{ba}	0.237 ^a	0.308 ^a	0.170 ^{ba}	0.148 ^a	0.200 ^{ba}
SE₁		0.0294	0.0313	0.0248	0.0147	0.0290	0.0229	0.0219	0.0187	0.0122
CD₁ at 1%		0.1318	0.1407	0.1112	0.066	0.1303	0.1028	0.0876	0.0841	0.0547
SE₂		0.0056								
CD₂ at 1%		0.0209								
SE₃		0.0238								
CD₃ at 1%		0.0660								

((‘a’-‘a’, ‘b’-‘b’, ‘c’-‘c’, ‘d’-‘d’, ‘ba’-‘ba’, ‘bc’-‘bc’ are non significant at ($p \leq 0.01$); ‘a’-‘b’, ‘b’-‘c’, ‘c’-‘d’, ‘b’-‘ba’, ‘a’-‘ba’, ‘c’-‘ba’ are significant at ($p \leq 0.01$)). (SE₁ and CD₁ = Effect of treatment combination, individual temperature and screw speed on bulk density. SE₂ and CD₂ = Effect of temperature and treatment combination on bulk density. SE₃ and CD₃ = Effect of treatment combination, temperature and screw speed on bulk density.)).

Table 4.10: Effect of flour composition, temperature of extrusion and the screw speed on the Water Absorption Index of the Tuber

crops extrudates.

Treatments	Flour composition (Arrowroot: Lesser Yam: Potato)	130°C			150°C			170°C		
		330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm
T1	0:50:50	4.53 ^c	3.73 ^c	3.73 ^c	4.67 ^a	4.93 ^{ba}	3.80 ^d	5.00 ^a	4.53 ^a	3.00 ^c
T2	10:40:50	4.23 ^d	4.27 ^a	4.27 ^b	3.93 ^b	4.33 ^{bc}	4.07 ^{cd}	4.00 ^c	3.53 ^{bc}	4.53 ^{ba}
T3	20:30:50	5.53 ^a	4.13 ^{ba}	4.20 ^b	2.73 ^c	4.13 ^{bc}	4.00 ^{cd}	3.00 ^d	4.27 ^{ba}	4.40 ^b
T4	30:20:50	4.80 ^{cb}	3.20 ^d	4.40 ^{ba}	3.73 ^b	5.87 ^a	5.40 ^a	4.93 ^{ba}	4.87 ^a	4.80 ^{ba}
T5	40:10:50	4.80 ^{cb}	4.40 ^a	4.80 ^a	3.87 ^b	4.73 ^{cb}	4.47 ^{cb}	4.20 ^c	3.40 ^c	5.00 ^a
T6	50:0:50	4.87 ^b	3.83 ^{bc}	3.53 ^c	3.60 ^b	4.40 ^c	4.60 ^b	4.40 ^{bc}	3.00 ^c	4.87 ^{ba}
SE₁		0.0655	0.0821	0.1025	0.1306	0.2201	0.1204	0.1327	0.1725	0.1333
CD₁ at 1%		0.2938	0.377	0.4597	0.5857	0.9865	0.5401	0.5951	0.7734	0.5976
SE₂		0.0314								
CD₂ at 1%		0.1166								
SE₃		0.1333								
CD₃ at 1%		0.3694								

((‘a’-‘a’, ‘b’-‘b’, ‘c’-‘c’, ‘d’-‘d’, ‘cb’-‘cb’, ‘cd’-‘cd’ are non significant at ($p \leq 0.01$); ‘a’-‘b’, ‘b’-‘c’, ‘c’-‘d’, ‘c’-‘cd’, ‘c’-‘bc’, ‘a’-‘ba’, ‘c’-‘ba’ are significant at ($p \leq 0.01$)). (SE₁ and CD₁ = Effect of treatment combination, individual temperature and screw speed on water absorption index. SE₂ and CD₂ = Effect of temperature and treatment combination on water absorption index. SE₃ and CD₃ = Effect of treatment combination, temperature and screw speed on water absorption index.)).

of the extruded products. These results are in agreement with extrudates prepared from corn/soybean feed, texturized rice, broken rice flour:pineapple waste pulp powder:red gram powder, rice:sweet potato:yam, carrot pomace:rice flour:pulse powder, rice flour, wheat, mungbean and groundnut (Sahagun and Harper, 1980; Ding *et al.*, 2006; Kothakota *et al.*, 2013; Hazarika *et al.*, 2013; Kumar *et al.*, 2010; Hagenimana *et al.*, 2006 and Pathania *et al.*, 2013).

4.4.1.3 Water Absorption Index (WAI)

Fig. 4.12 (a)-(f) shows the surface plots of effect of temperature of extrusion ($^{\circ}\text{C}$) and screw speed (rpm) on the water absorption index of extrudates for treatment (a) T1, (b) T2, (c) T3, (d) T4, (e) T5 and (f) T6. The water absorption index for tuber crops extrudates were in the range of 3.00-5.87g/g for all the treatments (T1 to T6), at varied temperature of extrusion (130 to 170 $^{\circ}\text{C}$) and screw speed (330 to 390 rpm). Water absorption index for treatment T1 ranges from 3.00-4.93g/g, for T2 from 3.53-4.53g/g, for T3 from 2.73-5.53g/g, for T4 from 3.20-5.87g/g, for T5 from 3.40-5.00g/g and for from T6 3.00-4.87g/g respectively for all the treatments (T1 to T6), temperature of extrusion (130 to 170 $^{\circ}\text{C}$) and screw speed (330 to 390 rpm). As the temperature of extrusion increases from 130 $^{\circ}\text{C}$ to 170 $^{\circ}\text{C}$, the water absorption index of the extrudates decreases for treatments T2, T3, T5 and T6. However in treatment T1 the water absorption index increases gradually from 130 $^{\circ}\text{C}$ to 170 $^{\circ}\text{C}$. Similarly in treatment T4 water absorption index increases gradually from 130 to 170 $^{\circ}\text{C}$, which can be observed from counter plots Fig. 4.13 (a)-(f). Similarly as the screw speed of the extruder increases from 330 to 390 rpm water absorption index decreases for treatments T1, T3 and T6. In treatment T2, T4 and T5 as the screw speed increases from 330 to 390 rpm the water absorption index increases up to 390 rpm, which can observe from counter plot Fig. 4.13 (a)-(f).

During extrusion cooking, lesser yam play important role in water absorption index of extrudates. As the lesser yam composition decreases in flour combination, water absorption index does not significantly change or it does not vary. Flour composition varied from T1 to T6 with decreasing the proportion of lesser yam. Water absorption index was shown in Table 4.9.

The second order polynomials equation shows the effect of temperature of extrusion ($^{\circ}\text{C}$) and screw speed (rpm) on the water absorption index of tuber crop extrudates for treatments T1, T2, T3, T4, T5 and T6 are given in Eq. (4.13), (4.14), (4.15), (4.16), (4.17) and (4.18) respectively.

$$\begin{aligned}
WAI_{T1} &= -76.931 + 0.276S - 3.086 \times 10^{-4}S^2 + 0.467T - 5.000 \times 10^{-4}ST - 9.444 \times 10^{-4}T^2 & (r^2= 0.997) \\
&\dots(4.13) \\
WAI_{T2} &= 34.713 - 0.129S + 1.419 \times 10^{-4}S^2 - 0.101T + 2.083 \times 10^{-4}ST - 6.944 \times 10^{-5}T^2 & (r^2= 0.997) \\
&\dots(4.14) \\
WAI_{T3} &= 34.713 - 0.129S + 1.419 \times 10^{-4}S^2 - 0.101T + 2.083 \times 10^{-4}ST - 6.944 \times 10^{-5}T^2 & (r^2= 0.991) \\
&\dots(4.15) \\
WAI_{T4} &= -17.388 - 0.036S + 3.641S^2 + 0.352T + 1.111 \times 10^{-4}ST - 1.247 \times 10^{-3}T^2 & (r^2= 0.982) \\
&\dots(4.16) \\
WAI_{T5} &= 75.050 - 0.317S + 13.827 \times 10^{-4}S^2 - 0.190T + 3.333 \times 10^{-4}ST + 1.944 \times 10^{-4}T^2 & (r^2= 0.994) \dots(4.17) \\
WAI_{T6} &= 119.051 - 0.565S + 6.296 \times 10^{-4}S^2 - 0.182T + 7.500 \times 10^{-4}ST - 2.916 \times 10^{-4}T^2 & (r^2= 0.987) \dots(4.18)
\end{aligned}$$

Where;

T=Temperature of barrel (extrusion) °C

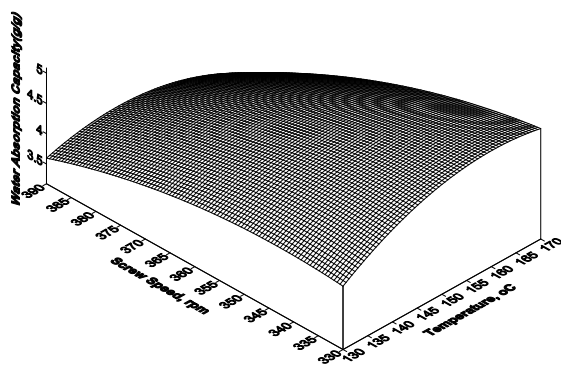
S= Screw speed (rpm)

WAI_{T1} , WAI_{T2} , WAI_{T3} , WAI_{T4} , WAI_{T5} and WAI_{T6} = Water absorption index at treatment T1, T2, T3, T4, T5 and T6 respectively.

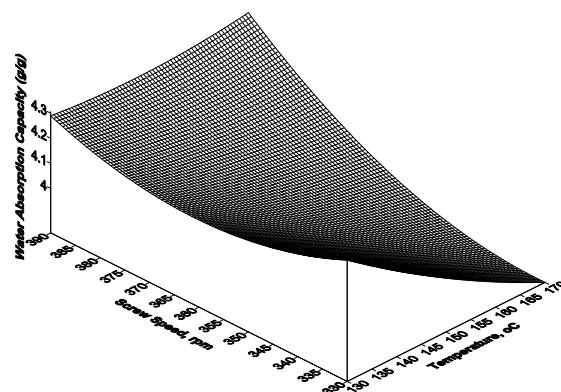
Table 4.10 and 4.8 (c) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the water absorption index of the tuber crops extrudates. It is clear from the table that water absorption index is significantly affected ($p \leq 0.01$) by the flour composition, screw speed and temperature. The interaction between the flour compositions, screw speed and temperature has a significant difference in the water absorption index. The interactions among independent variables significantly affected the WAI values ($P \leq 0.01$).

Increase in temperature resulted in decrease in water absorption index. Whereas further increase in water absorption index may be due to dextrinization of starch molecules at higher temperature, similar observations were reported by Mercier and Feillet (1975) for cereal products. Water absorption index increased with increase in screw speed, may be attributed to high mechanical shear and higher expansion due to gelatinization of starch molecules. Whereas further decrease in water absorption index may be because of plasticization of melt at higher moisture content (Ding *et al.*, 2006; Kumar *et al.*, 2010).

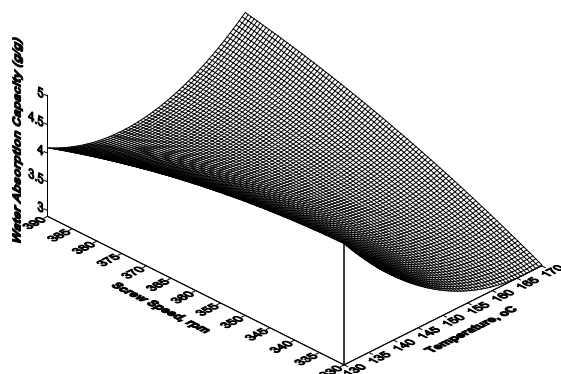
The combined effect of increase in barrel temperature (130-170°C) and screw speed (330-390 rpm) decreases the water absorption index for all the treatments i.e. T1 to T6 of tuber crops extrudates. These results are in consistent with the extruded products prepared from for broken rice flour:pineapple waste paste powder:red gram powder, pomace:rice flour:pulse powder, wheat:mungbean:groundnut, barley-tomato pomace (Kothakota *et al.*, 2013; Kumar *et al.*, 2010; Pathania *et al.*, 2013; Altan *et al.*, (2008)).



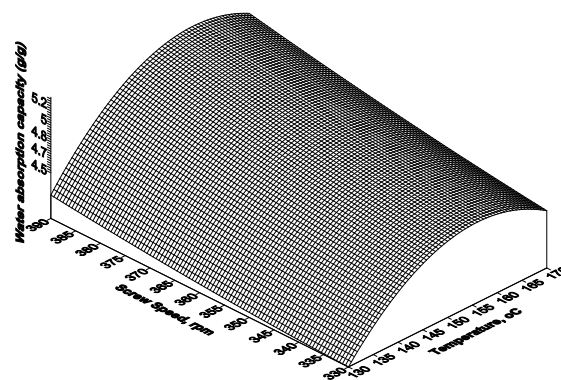
(a)T1



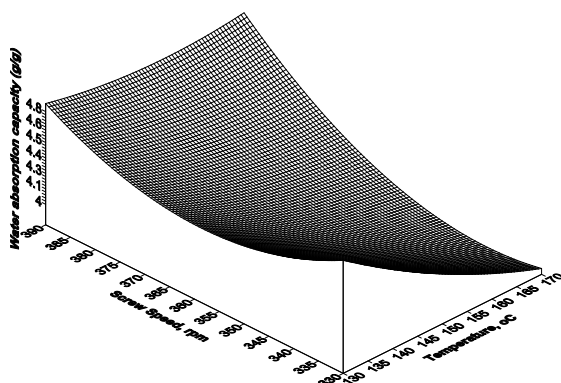
(b)T2



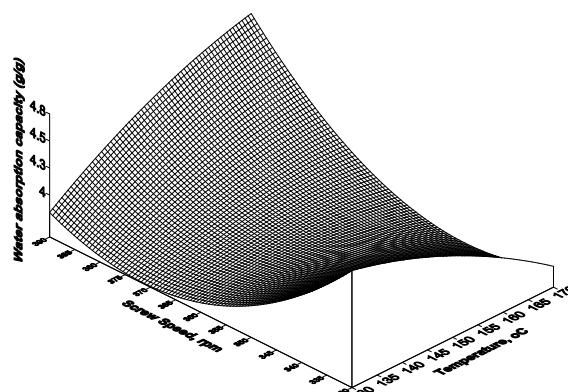
(c)T3



(d)T4



(e)T5



(f)T6

Fig. 4.12: Surface plots of Effect of Temperature of Extrusion, Screw Speed on Water Absorption Index of Tuber Crops based extrudates (a) For Treatment T1; (b) For Treatment T2; (c) For T For Treatment T3; (d) For Treatment T4; (e) For Treatment T5; (f)For Treatment T6.

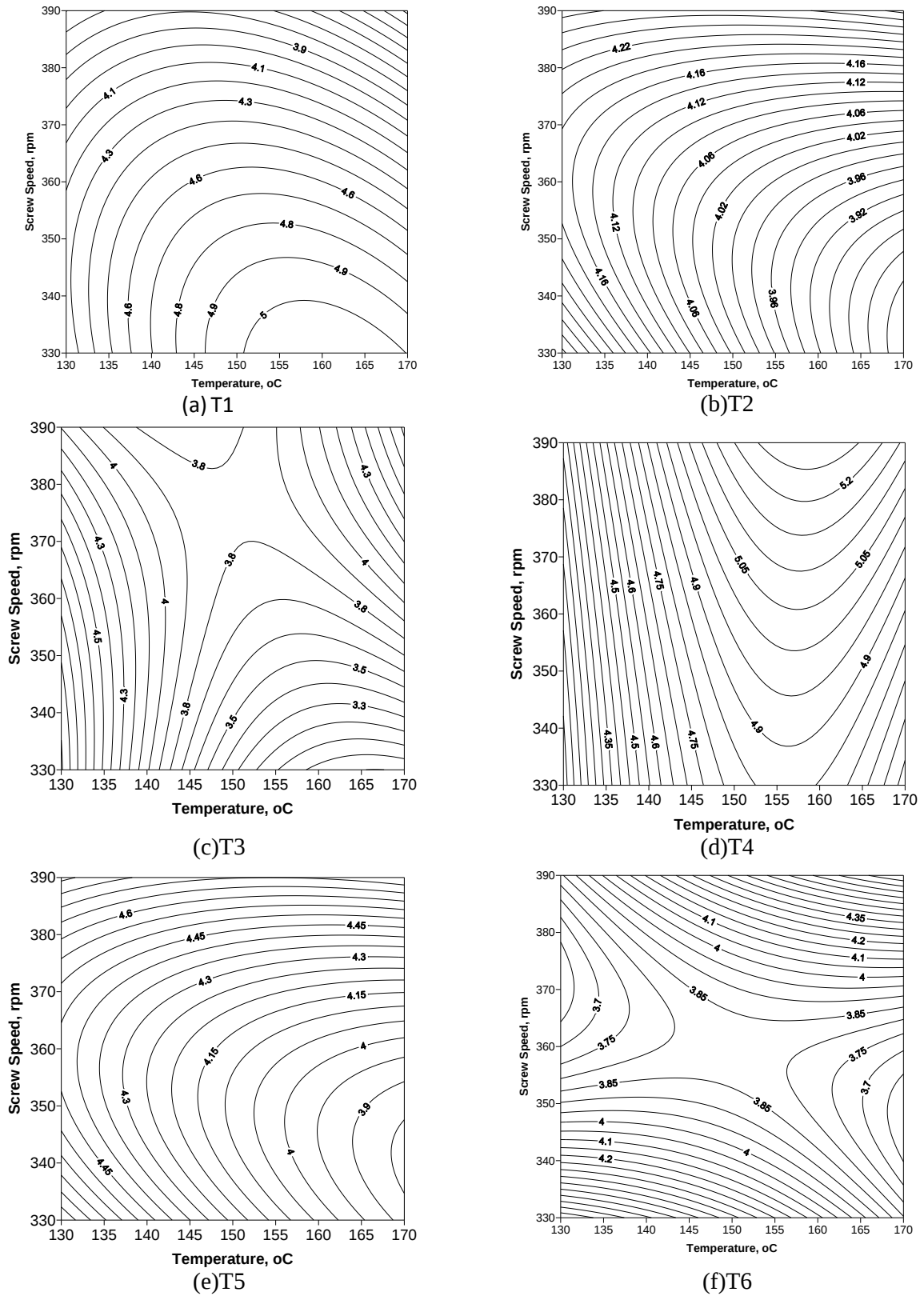


Fig. 4.13: Contour plots of Effect of Temperature of Extrusion, Screw Speed on Water Absorption Index of Tuber Crops based Extrudates (a) For Treatment T1; (b) For Treatment T2; (c) For T For Treatment T3; (d) For Treatment T4; (e) For Treatment T5; (f) For Treatment T6.

4.4.1.4 Water solubility index (WSI)

Fig. 4.14 (a)-(f) shows the surface plots of effect of temperature of extrusion (°C) and screw speed (rpm) on the water solubility index of extrudates for treatment (a) T1, (b) T2, (c) T3, (d) T4, (e) T5 and (f) T6. The water solubility index for tuber crops extrudates were in the range of 15.33-38.00% for all treatments (T1 to T6), varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Water solubility index for treatment T1 ranged from 30.66-38.00%, for T2 from 26.00-33.33%, for T3 from 22.66-32.00%, for T4 from 19.33-27.33%, for T5 from 16.00-23.33% and for T6 from 15.33-21.33% respectively. Increasing the extrusion temperature from 130°C to 170°C the water solubility index of the extrudates, decreases for treatments T1, T2, T3, T4, T5 and T6, which can observe from counter plots Fig. 4.15 (a)-(f). Similarly as the screw speed of the extruder increases from 330 to 390 rpm, water solubility index decreases for all the treatments, this can observe from counter plots Fig. 4.15 (a)-(f).

During extrusion cooking, lesser yam play an important role in water solubility index. As the lesser yam proportion decreases in flour composition from T1 to T6, the water solubility index of the extrudates decreases and vice versa. If lesser yam composition increases in flour composition then water solubility index also increases in extruded product which was shown in Table 4.11.

The second order polynomials equation shows the effect of temperature of extrusion (°C) and screw speed (rpm) on the water solubility index of tuber crop extrudates for treatments T1, T2, T3, T4, T5 and T6 are given in Eq. (4.19), (4.20), (4.21), (4.22), (4.23) and (4.24) respectively.

$$WSI_{T1} = 66.924 + 0.105S - 2.487 \times 10^{-4}S^2 - 0.422T - 1.293 \times 10^{-15}ST + 1.111 \times 10^{-4}T^2 \quad (r^2 = 0.999) \dots(4.19)$$

$$WSI_{T2} = 16.436 - 0.155S + 3.691 \times 10^{-4}S^2 + 0.795T - 1.106 \times 10^{-3}ST - 1.656 \times 10^{-3}T^2 \quad (r^2 = 0.999) \dots(4.20)$$

$$WSI_{T3} = -26.500 - 0.622S + 8.654 \times 10^{-4}S^2 + 2.433T - 2.749 \times 10^{-4}ST - 8.061 \times 10^{-3}T^2 \quad (r^2 = 0.995) \dots(4.21)$$

$$WSI_{T4} = -23.304 + 0.405S - 3.722 \times 10^{-4}S^2 - 0.088T - 1.387 \times 10^{-3}ST + 1.662 \times 10^{-3}T^2 \quad (r^2 = 0.999) \dots(4.22)$$

$$WSI_{T5} = -57.601 + 0.496S - 9.851 \times 10^{-4}S^2 - 0.733T - 1.108 \times 10^{-3}ST + 3.608 \times 10^{-3}T^2 \quad (r^2 = 0.997) \dots(4.23)$$

$$WSI_{T6} = 132.571 - 0.496S + 4.907 \times 10^{-4}S^2 - 0.111T + 5.583 \times 10^{-4}ST - 5.583 \times 10^{-4}T^2 \quad (r^2 = 0.993) \dots(4.24)$$

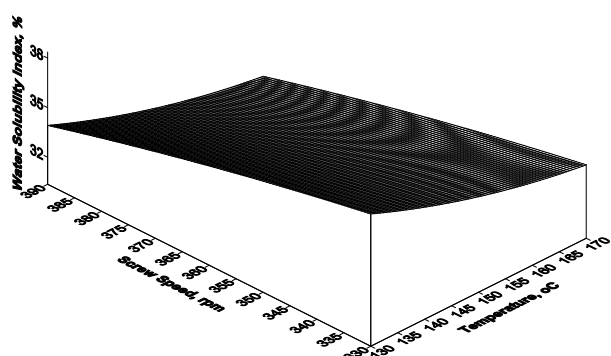
Where;

T=Temperature of barrel (extrusion) °C

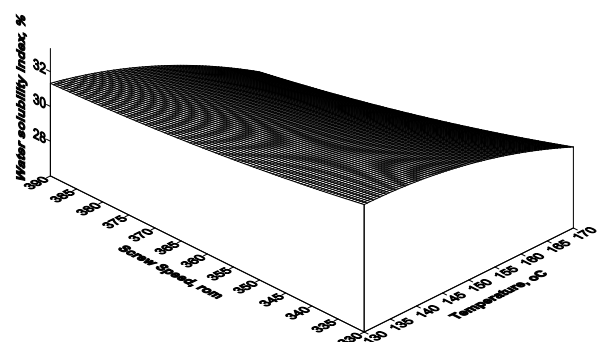
S= Screw speed (rpm)

WSI_{T1} , WSI_{T2} , WSI_{T3} , WSI_{T4} , WSI_{T5} and WSI_{T6} = Water solubility index at treatment T1, T2, T3, T4, T5 and T6 respectively.

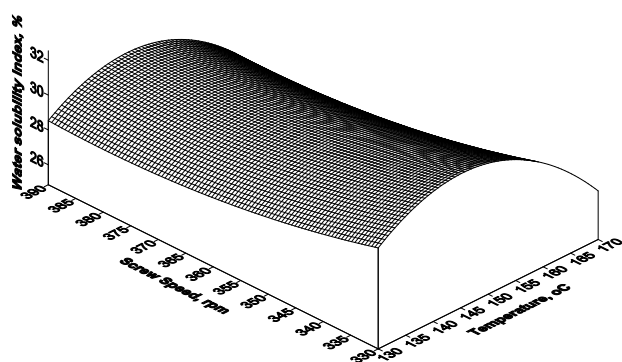
Table 4.11 and 4.8 (d) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the water solubility index of the tuber crops



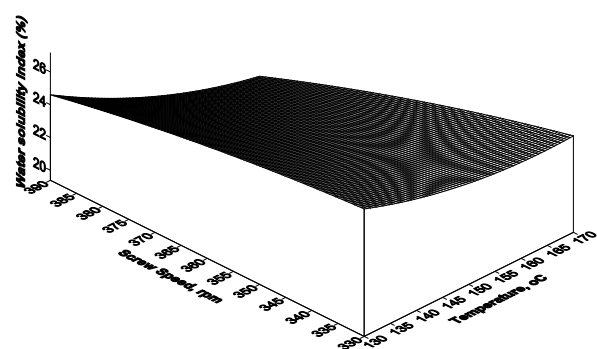
(a)T1



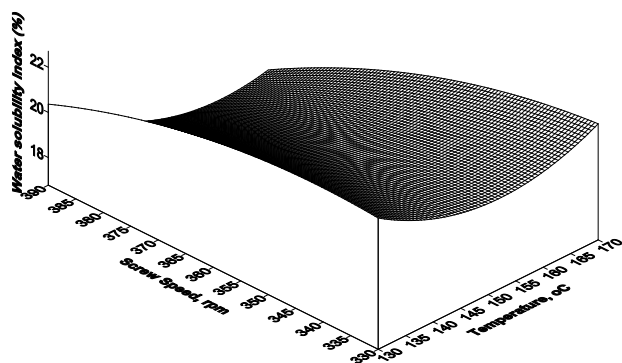
(b)T2



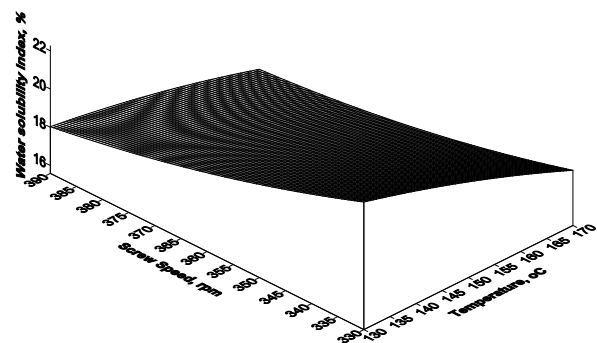
(c)T3



(d)T4

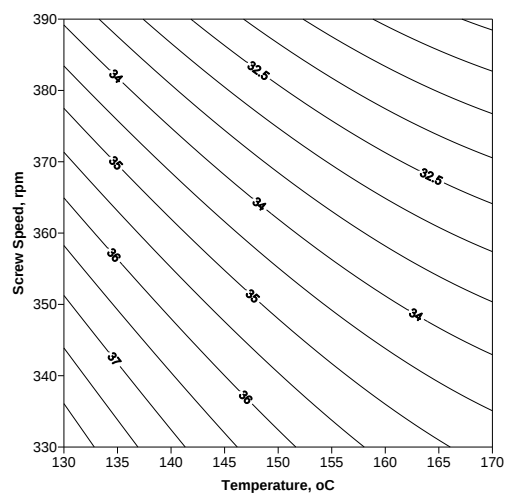


(e)T5

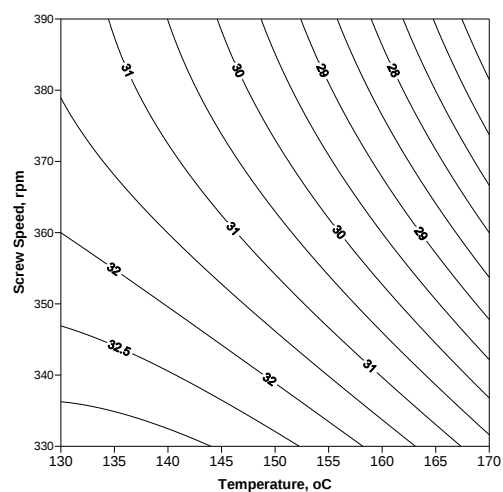


(f)T6

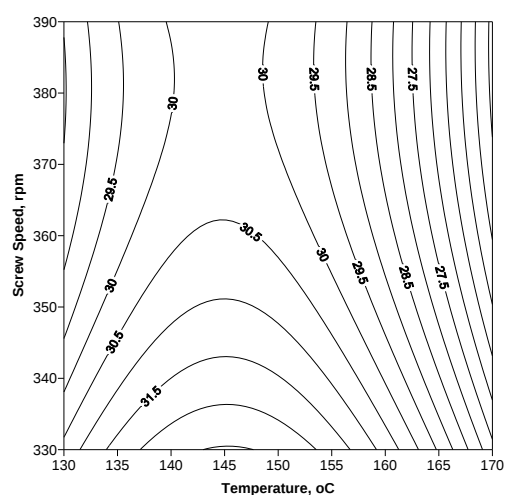
Fig. 4.14: Surface plots of Effect of Temperature of Extrusion, Screw Speed on Water solubility Index of Tuber Crops based extrudates (a) For Treatment T1; (b) For Treatment T2; (c) For T For Treatment T3; (d) For Treatment T4; (e) For Treatment T5; (f)For Treatment T6.



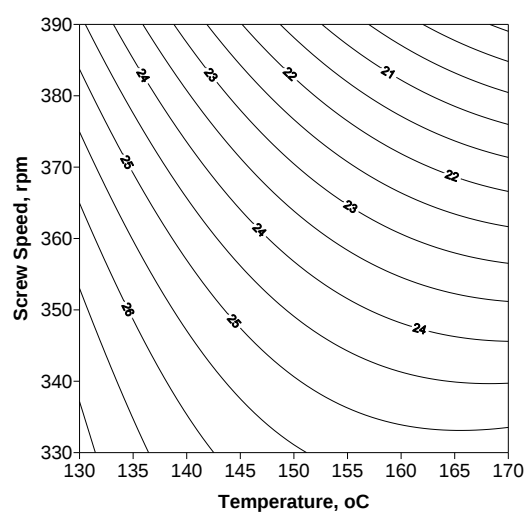
(a)T1



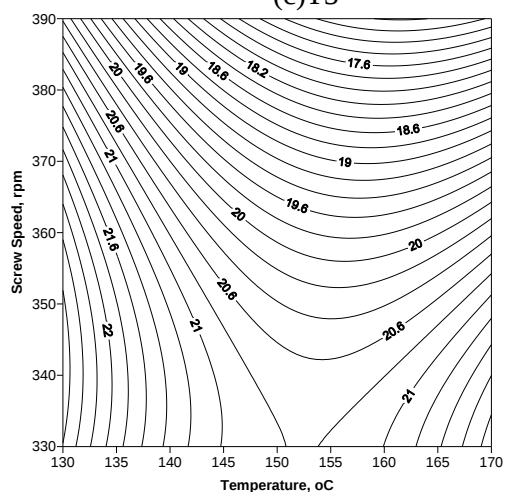
(b)T2



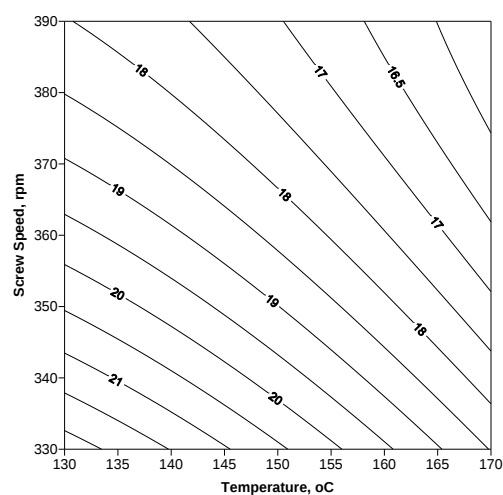
(c)T3



(d)T4



(e)T5



(f)T6

Fig. 4.15: Contour plots of Effect of Temperature of Extrusion, Screw Speed on Water solubility Index of Tuber Crops based Extrudates (a) For Treatment T1; (b) For Treatment T2; (c) For T For Treatment T3; (d) For Treatment T4; (e) For Treatment T5; (f) For Treatment T6.

Table 4.11: Effect of flour composition, temperature of extrusion and the screw speed on the Water Solubility Index of the Tuber crops extrudates.

Treatments	Flour composition (Arrowroot: Lesser Yam: Potato)	130°C			150°C			170°C		
		330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm
T1	0:50:50	38.00 ^a	36.67 ^a	34.00 ^a	36.66 ^a	34.00 ^a	31.33 ^a	34.66 ^a	32.66 ^a	30.66 ^a
T2	10:40:50	33.33 ^{ba}	32.00 ^{ba}	31.33 ^{ba}	32.66 ^a	30.66 ^{ba}	29.33 ^{ba}	30.66 ^{ba}	28.00 ^{ba}	26.00 ^b
T3	20:30:50	32.00 ^{ba}	29.33 ^b	26.66 ^{bc}	30.00 ^{ba}	28.66 ^{ba}	34.00 ^{bac}	28.66 ^{ba}	26.66 ^{ba}	22.66 ^{cb}
T4	30:20:50	27.33 ^{bc}	26.00 ^{bc}	24.66 ^c	25.33 ^{bc}	24.00 ^{bc}	21.33 ^{bc}	25.33 ^{bc}	22.66 ^{bc}	19.33 ^{cd}
T5	40:10:50	23.33 ^c	20.66 ^c	21.33 ^{dc}	21.33 ^{dc}	19.33 ^{dc}	17.33 ^c	20.66 ^{dc}	22.66 ^c	16.00 ^d
T6	50:0:50	21.33 ^c	20.00 ^c	18.66 ^d	23.33 ^d	16.00 ^d	16.66 ^c	16.66 ^d	18.66 ^c	15.33 ^d
SE₁		1.5444	1.4246	1.2232	1.5006	1.7213	2.0330	1.7213	1.6688	0.9888
CD₁ at 1%		6.9221	6.3853	5.4826	6.7258	7.7152	9.1122	3.1692	7.4800	4.431
SE₂		0.3614								
CD₂ at 1%		1.3406								
SE₃		1.5332								
CD₃ at 1%		4.2486								

((‘a’-‘a’, ‘b’-‘b’, ‘c’-‘c’, ‘d’-‘d’, ‘ba’-‘ba’, ‘bc’-‘bc’, ‘dc’-‘dc’, ‘cd’-‘cd’ are non significant at ($p \leq 0.01$); ‘a’-‘b’, ‘b’-‘c’, ‘c’-‘d’, ‘b’-‘ba’, ‘a’-‘ba’, ‘c’-‘bc’, ‘b’-‘bc’, ‘c’-‘dc’, ‘b’-‘bac’ are significant at ($p \leq 0.01$)). (SE₁ and CD₁ = Effect of treatment combination, individual temperature and screw speed on water solubility index. SE₂ and CD₂ = Effect of temperature and treatment combination on water solubility index. SE₃ and CD₃ = Effect of treatment combination, temperature and screw speed on water solubility index.)).

extrudates. It is clear from the table; water solubility index is significantly affected ($p \leq 0.01$) by the flour composition, screw speed and temperature. The interactions among independent variables significantly affected the WSI values ($p \leq 0.01$)

Increasing temperature would increase the degree of starch gelatinization that could increase the amount of soluble starch resulting in an increase in WSI. Positive relationship of WSI and temperature was also achieved by Ding *et al.*, (2005) in extruded products. Water solubility index decreased initially and increased further with increase in temperature, which may be attributed to increased dextrinization at higher temperature and it causes more solubility due to change in the starch granule structure (Mercier and Feillet, 1975). Water solubility index increases with increase in screw speed is due to high mechanical shear exerted on extrudates. Similar observations were reported by Ding *et al.*, (2005) for rice based expanded snacks.

There was a decrease in water solubility index with the increase in screw speed which may be because of high mechanical shear exerted on extrudates, whereas further decrease in water soluble index with the increase in screw speed may be the result of higher expansion of the product. Water solubility index decreased initially and increased further with increase in temperature, which may be attributed to the similar variation of lateral expansion of the extrudates with increase in temperature. The results obtained for water solubility index are in line with the results obtained for lateral expansion (Kumar *et al.*, 2010) for carrot pomace, rice flour and pulse power blend.

The combined effect of increase in barrel temperature (130-170°C) and screw speed (330-390 rpm) decreases the water solubility index for all the treatments i.e. T1 to T6 of tuber crops extrudates. Increase in barrel temperature with increase in screw speed decreases water solubility index of the extruded products for broken rice flour:pineapple waste paste powder:red gram powder, pomace:rice flour:pulse powder, wheat:mungbean:groundnut, barley-tomato pomace (Kothakota *et al.*, 2013; Kumar *et al.*, 2010; Pathania *et al.*, 2013; Altan *et al.*, (2008)).

4.4.1.5 Hardness (HR)

Fig. 4.16 (a)-(f) shows the surface plots of effect of temperature of extrusion (°C) and screw speed (rpm) on the hardness of extrudates for treatment (a) T1, (b) T2, (c) T3, (d) T4, (e) T5 and (f) T6. The hardness for tuber crops extrudates were in the range of 1080.00-19976.67 g for all treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Hardness for treatment T1 ranged from 1080.00-

2785.88g, for T2 from 1250.00-6051.67g, for T3 from 1085.00-7920.00g, for T4 from 1561.67-14855.00g, for T5 from 3553.33-11945.00g and for T6 from 2275.00-19976.67g respectively. The temperature of extrudates increases from 130°C to 170°C, the hardness of the extrudates decreases for treatments T2, T3, T4, T5 and T6. Similarly if screw speed of the extruder increases from 330 to 390 rpm, hardness decreases for all the treatments which can be observed from counter plots fig. 4.17 (a)-(f).

During extrusion cooking, lesser yam play important role in hardness of the extrudates. As the lesser yam decreases in flour combination from T1 to T6, hardness of extrudates increases during extrusion cooking and vice versa.

The second order polynomial equations shows the effect of temperature of extrusion (°C) and screw speed (rpm) on the hardness of tuber crop extrudates for treatments T1, T2, T3, T4, T5 and T6 are given in Eq. (4.25), (4.26), (4.27), (4.28), (4.29) and (4.30) respectively.

$$HR_{T1} = 39888.601 - 99.849S + 0.036S^2 - 252.083T + 0.435ST + 0.338T^2 \quad (r^2 = 0.964) \quad \dots(4.25)$$

$$HR_{T2} = 325623.971 - 1300.819S + 1.325S^2 - 1100.111T + 2.114ST + 1.037T^2 \quad (r^2 = 0.990) \quad \dots(4.26)$$

$$HR_{T3} = 365303.667 - 1149.668S + 1.160S^2 - 21982.863T + 1.892ST + 4.209T^2 \quad (r^2 = 0.927) \quad \dots(4.27)$$

$$HR_{T4} = 676760.462 - 2758.975S + 2.658S^2 - 22043.055T + 4.993ST + 0.502T^2 \quad (r^2 = 0.923) \quad \dots(4.28)$$

$$HR_{T5} = 342467.103 - 1115.104S + 1.189S^2 - 1566.529T + 0.1423ST + 3.002T^2 \quad (r^2 = 0.996) \quad \dots(4.29)$$

$$HR_{T6} = 703055.177 - 3405.033S + 0.3715S^2 - 879.811T + 4.668ST - 3.244T^2 \quad (r^2 = 0.826) \quad \dots(4.30)$$

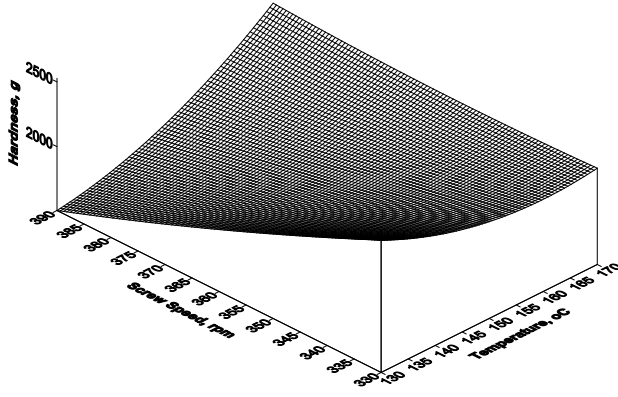
Where;

T=Temperature of barrel (extrusion) °C

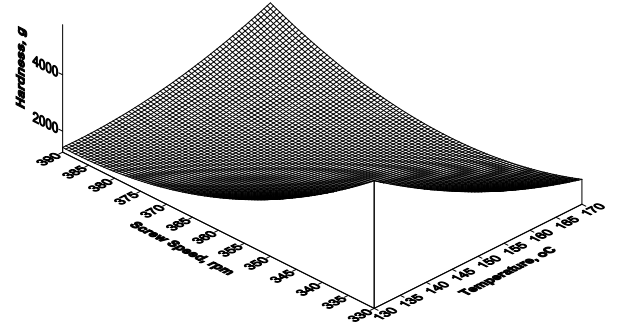
S= Screw speed (rpm)

HR_{T1}, HR_{T2}, HR_{T3}, HR_{T4}, HR_{T5} and HR_{T6} = Hardness at treatment T1, T2, T3, T4, T5 and T6 respectively.

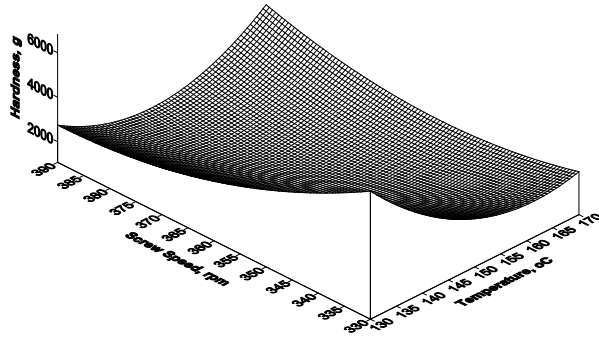
Table 4.12 and 4.8 (e) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the hardness of the tuber crops extrudates. It is clear from the table, hardness is a significantly affected by ($p \leq 0.01$) on the flour composition, screw speed and temperature. The interaction between the flour compositions, screw speed and temperature has a significant difference in the hardness. The interactions among independent variables have significant effect on the hardness values ($p \leq 0.01$). As the lesser yam decreased in flour composition from T1 to T6, hardness of extruded products significantly ($p \leq 0.01$) increased.



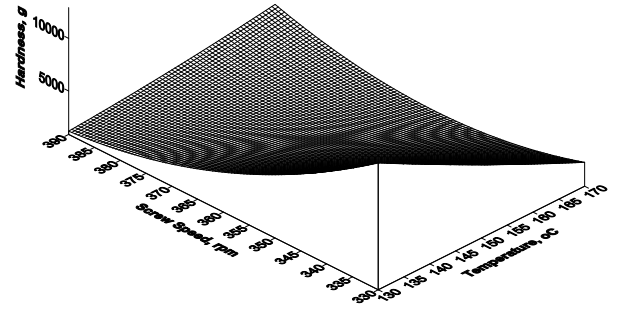
(a)T1



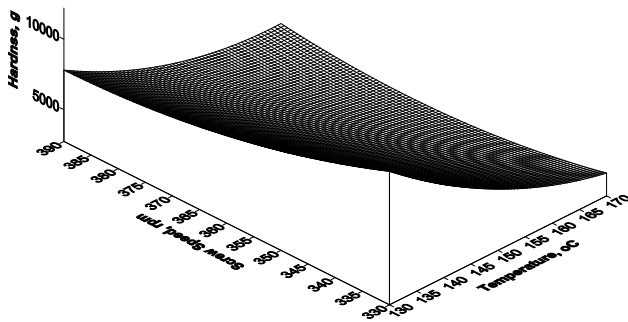
(b)T2



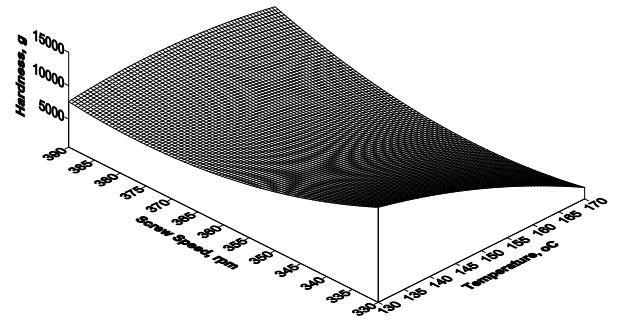
(c)T3



(d)T4

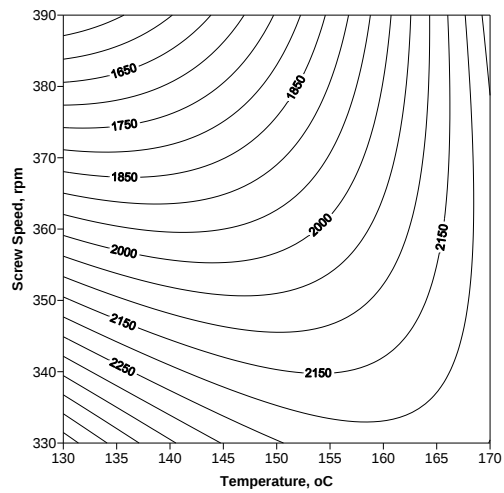


(e)T5

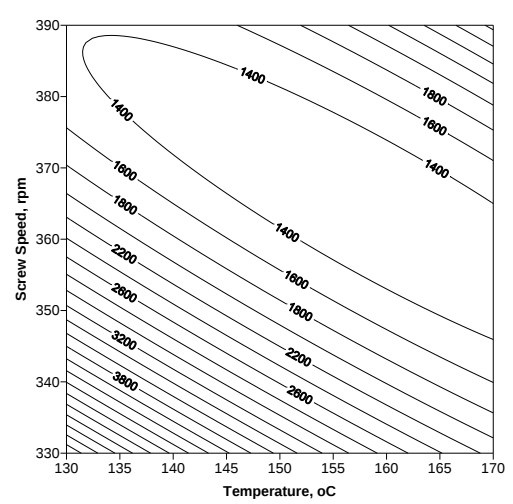


(f)T6

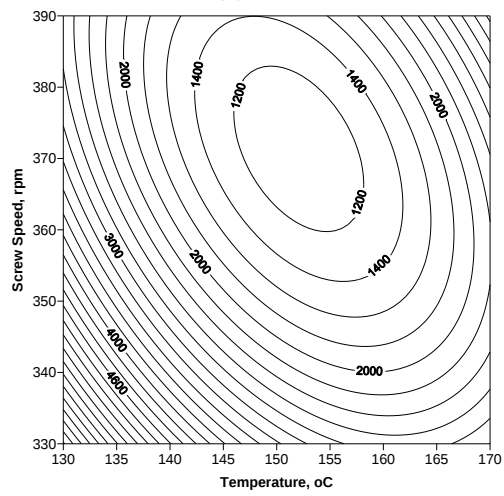
Fig. 4.16: Surface plots of Effect of Temperature of Extrusion, Screw Speed on Hardness of Tuber Crops based extrudates (a) For Treatment T1; (b) For Treatment T2; (c) For T For Treatment T3; (d) For Treatment T4; (e) For Treatment T5; (f)For Treatment T6.



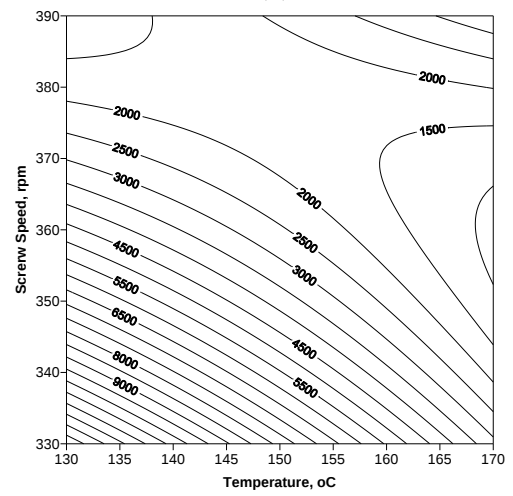
(a)T1



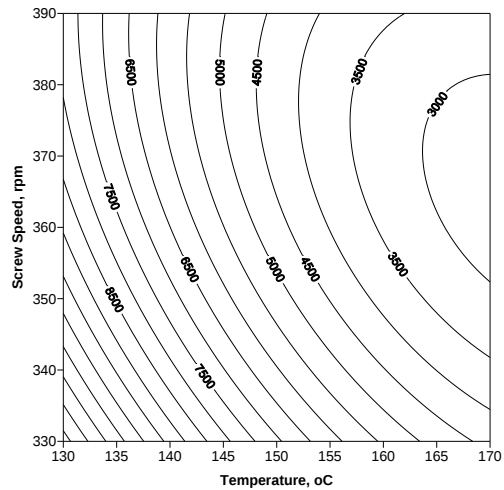
(b)T2



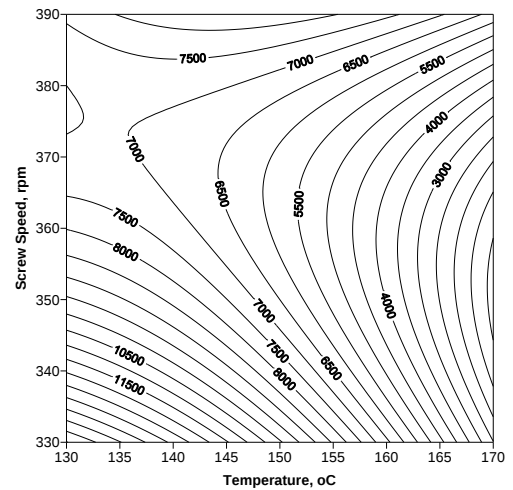
(c)T3



(d)T4



(e)T5



(f)T6

Fig. 4.17: Contour plots of Effect of Temperature of Extrusion, Screw Speed on Hardness of Tuber Crops based Extrudates (a) For Treatment T1; (b) For Treatment T2; (c) For T For Treatment T3; (d) For Treatment T4; (e) For Treatment T5; (f) For Treatment T6.

extrudates. It is clear from the table; water solubility index is significantly affected ($p \leq 0.01$) by the flour composition, screw speed and temperature. The interactions among independent variables significantly affected the WSI values ($p \leq 0.01$)

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The combined effect of increase in barrel temperature (130-170°C) and screw speed (330-390 rpm) decreases the water solubility index for all the treatments i.e. T1 to T6 of tuber crops extrudates. Increase in barrel temperature with increase in screw speed decreases water solubility index of the extruded products for broken rice flour:pineapple waste paste powder:red gram powder, pomace:rice flour:pulse powder, wheat:mungbean:groundnut, barley-tomato pomace (Kothakota *et al.*, 2013; Kumar *et al.*, 2010; Pathania *et al.*, 2013; Altan *et al.*, (2008)).

4.4.1.5 Hardness (HR)

Fig. 4.16 (a)-(f) shows the surface plots of effect of temperature of extrusion (°C) and screw speed (rpm) on the hardness of extrudates for treatment (a) T1, (b) T2, (c) T3, (d) T4, (e) T5 and (f) T6. The hardness for tuber crops extrudates were in the range of 1080.00-19976.67 g for all treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Hardness for treatment T1 ranged from 1080.00-

2785.88g, for T2 from 1250.00-6051.67g, for T3 from 1085.00-7920.00g, for T4 from 1561.67-14855.00g, for T5 from 3553.33-11945.00g and for T6 from 2275.00-19976.67g respectively. The temperature of extrudates increases from 130°C to 170°C, the hardness of the extrudates decreases for treatments T2, T3, T4, T5 and T6. Similarly if screw speed of the extruder increases from 330 to 390 rpm, hardness decreases for all the treatments which can be observed from counter plots fig. 4.17 (a)-(f).

During extrusion cooking, lesser yam play important role in hardness of the extrudates. As the lesser yam decreases in flour combination from T1 to T6, hardness of extrudates increases during extrusion cooking and vice versa.

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$$HR_{T1} = 39888.601 - 99.849S + 0.036S^2 - 252.083T + 0.435ST + 0.338T^2 \quad (r^2 = 0.964) \quad \dots(4.25)$$

$$HR_{T2} = 325623.971 - 1300.819S + 1.325S^2 - 1100.111T + 2.114ST + 1.037T^2 \quad (r^2 = 0.990) \quad \dots(4.26)$$

$$HR_{T3} = 365303.667 - 1149.668S + 1.160S^2 - 21982.863T + 1.892ST + 4.209T^2 \quad (r^2 = 0.927) \quad \dots(4.27)$$

$$HR_{T4} = 676760.462 - 2758.975S + 2.658S^2 - 22043.055T + 4.993ST + 0.502T^2 \quad (r^2 = 0.923) \quad \dots(4.28)$$

$$HR_{T5} = 342467.103 - 1115.104S + 1.189S^2 - 1566.529T + 0.1423ST + 3.002T^2 \quad (r^2 = 0.996) \quad \dots(4.29)$$

$$HR_{T6} = 703055.177 - 3405.033S + 0.3715S^2 - 879.811T + 4.668ST - 3.244T^2 \quad (r^2 = 0.826) \quad \dots(4.30)$$

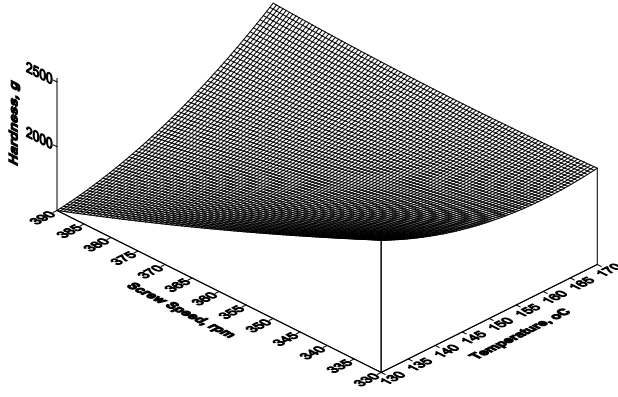
Where;

T=Temperature of barrel (extrusion) °C

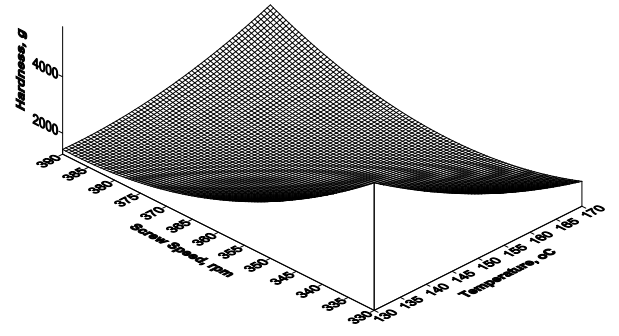
S= Screw speed (rpm)

HR_{T1}, HR_{T2}, HR_{T3}, HR_{T4}, HR_{T5} and HR_{T6} = Hardness at treatment T1, T2, T3, T4, T5 and T6 respectively.

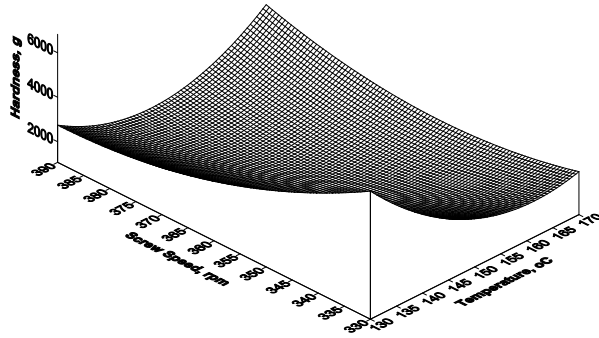
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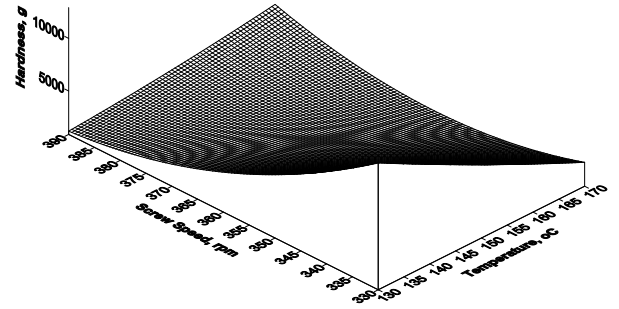
(a)T1



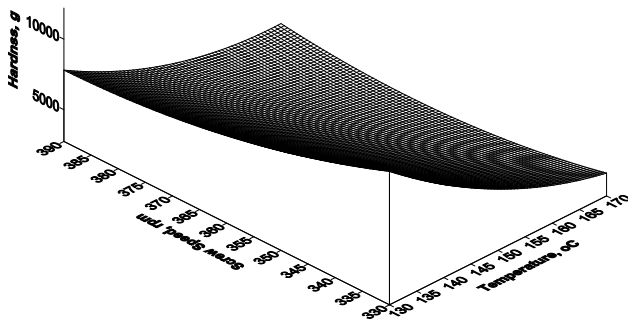
(b)T2



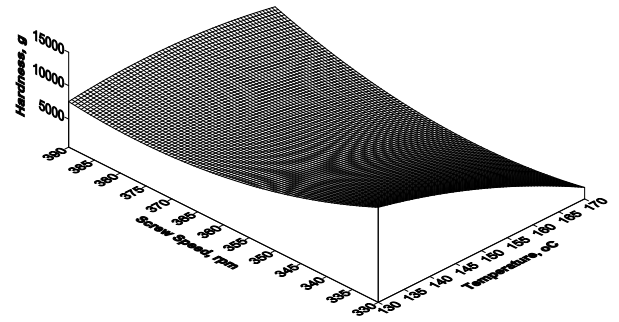
(c)T3



(d)T4

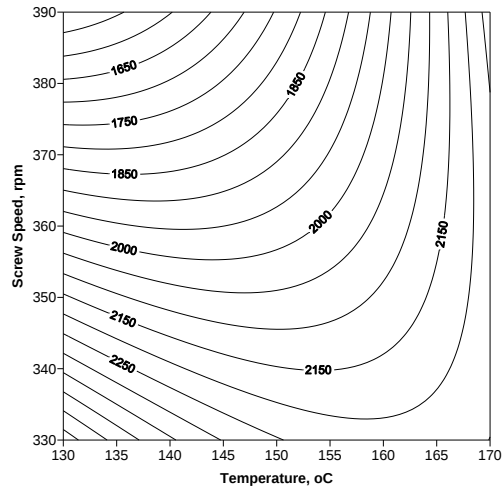


(e)T5

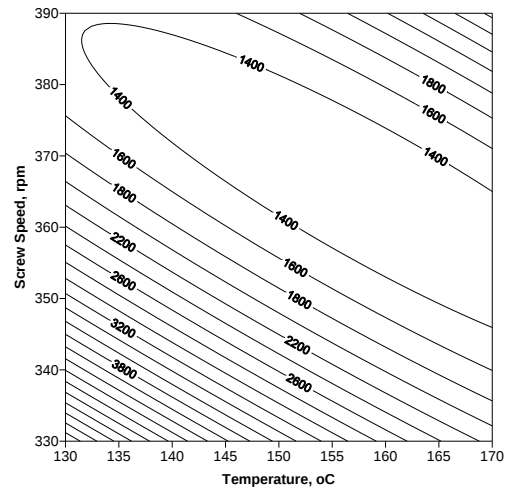


(f)T6

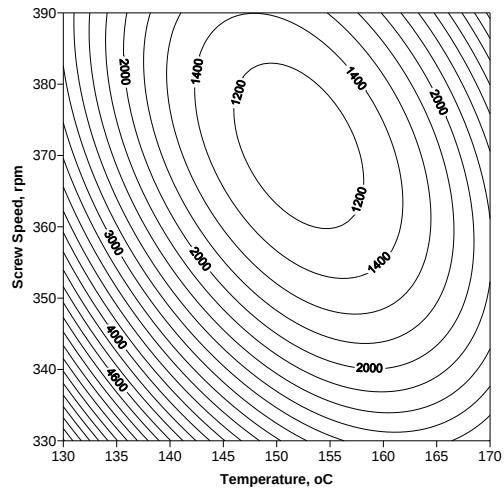
Fig. 4.16: Surface plots of Effect of Temperature of Extrusion, Screw Speed on Hardness of Tuber Crops based extrudates (a) For Treatment T1; (b) For Treatment T2; (c) For T For Treatment T3; (d) For Treatment T4; (e) For Treatment T5; (f)For Treatment T6.



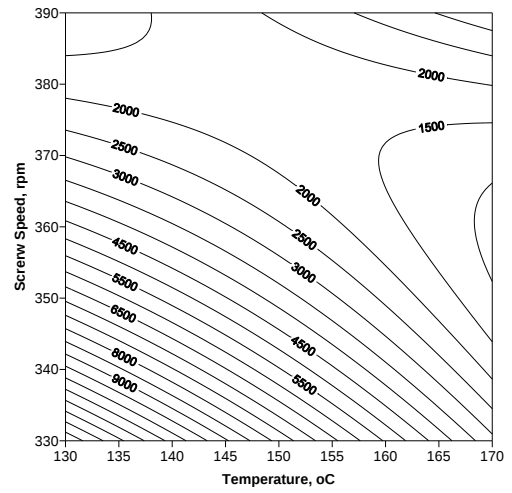
(a)T1



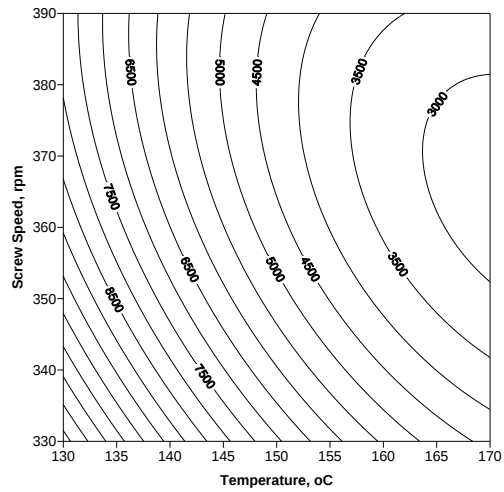
(b)T2



(c)T3



(d)T4



(e)T5

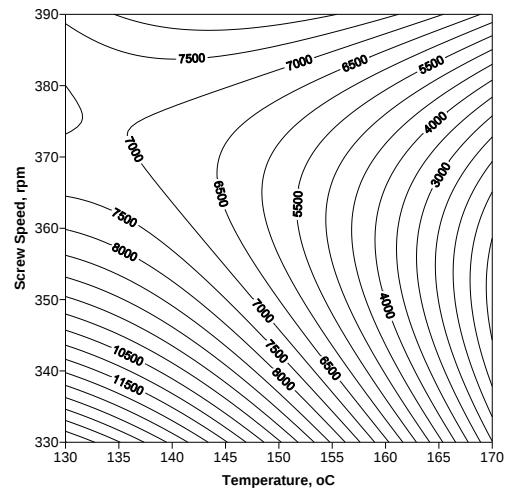


Table 4.12: Effect of flour composition, temperature of extrusion and the screw speed on the Hardness (g) of the Tuber crops

extrudates.

Treatments	Flour composition (Arrowroot: Lesser Yam: Potato)	130°C			150°C			170°C		
		330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm
T1	0:50:50	2,785.00 ^d	2,155.00 ^b	1,080.00 ^b	1,656.67 ^c	1,800.00 ^b	2,525.00 ^b	2,591.67 ^a	2,231.67 ^{ba}	1,931.67 ^a
T2	10:40:50	6,051.67 ^d	2,153.33 ^b	1,411.67 ^b	3,356.67 ^{bc}	1,250.00 ^b	2,108.33 ^b	2,055.00 ^a	1,758.33 ^b	2,490.00 ^a
T3	20:30:50	7,920.00 ^c	1,866.67 ^b	3,540.00 ^b	2,313.33 ^c	2,543.33 ^b	1,085.00 ^b	2,843.33 ^a	2,810.00 ^{ba}	3,005.00 ^a
T4	30:20:50	14,855.00 ^b	1,561.67 ^b	2,360.00 ^b	6,505.00 ^{ba}	3,716.67 ^b	2,268.33 ^b	2,546.67 ^a	2,828.33 ^{ba}	2,035.00 ^a
T5	40:10:50	11,945.00 ^c	8,766.67 ^a	8,251.67 ^a	7,665.00 ^a	4,938.33 ^{ba}	3,553.33 ^b	4,060.00 ^a	2,711.67 ^{ba}	3,783.33 ^a
T6	50:0:50	19,976.67 ^a	2,275.00 ^b	8,376.67 ^a	4,490.00 ^{bac}	8,590.00 ^a	11,090.00 ^a	3,150.00 ^a	4,022.67 ^a	2,753.33 ^a
SE₁		1306	476.66	1115.29	738.34	949.73	642.34	494.78	456.41	458.19
CD₁ at 1%		5853	2136.40	4998.72	3309.23	4256.71	2878.96	2217.60	2045.62	2053.60
SE₂		189.0647								
CD₂ at 1%		701.3300								
SE₃		802.1334								
CD₃ at 1%		2222.7117								

((‘a’-‘a’, ‘b’-‘b’, ‘c’-‘c’, ‘d’-‘d’, ‘ba’-‘ba’, ‘bc’-‘bc’ are non significant at ($p \leq 0.01$); ‘a’-‘b’, ‘b’-‘c’, ‘c’-‘d’, ‘a’-‘ab’, ‘b’-‘ba’, ‘b’-‘bc’, ‘a’-‘ba’, ‘b’-‘bac’ are significant at ($p \leq 0.01$)). (SE₁ and CD₁ = Effect of treatment combination, individual temperature and screw speed on hardness. SE₂ and CD₂ = Effect of temperature and treatment combination on hardness. SE₃ and CD₃ = Effect of treatment combination, temperature and screw speed on hardness.)).

It may be observed that hardness decreased with the increase in screw speed. Similar decrease in hardness with increased screw speed due to lower melt density was observed by Ding *et al.* (2006) for wheat based expanded snacks.

The combined effect of increase in barrel temperature (130-170°C) and screw speed (330-390 rpm) decreases the hardness for all the treatments i.e. T1 to T6 of tuber crops extrudates. Increase in barrel temperature with increase in screw speed decreases hardness of the extruded products for wheat:mugbean:groundnut, pomace:riceflour:pulse powder, broken rice flour:pineapple waste pulp powder:red gram powder (Pathania *et al.*, 2013; Kumar *et al.*, 2010 and Kothakota *et al.*, 2013).

4.4.2 Nutritional Properties of extrudates

4.4.2.1 Protein Content

Table 4.13 shows the effect of flour composition, temperature of extrusion and the screw speed on the protein content (%) of the tuber crops extrudates. The protein of extrudates varied between 1.52 and 4.67% for all treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Protein content for treatment T1 ranged from 2.86-4.67%, for T2 from 2.45-4.55%, for T3 from 2.33-4.43%, for T4 from 2.04-4.03%, for T5 from 1.87-2.63% and for T6 from 1.52-2.16% respectively. It was maximum (4.67 %) at 130°C barrel temperature, screw speed is 330 rpm and feed composition level is T1 and was minimum (1.52 %) at 170°C barrel temperature, screw speed is 390 rpm and feed composition level is T6. As the proportion of lesser yam decreased in feed composition which may result in decreased protein content of extruded in extrusion cooking and vice versa.

Table 4.13 and 4.14 (a) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the protein content of the tuber crops extrudates. It is clear from the table that protein content has a significant effect ($p \leq 0.01$) on the flour composition, screw speed and temperature. The interactions among independent variables significantly affected the protein content values of extrudates ($p \leq 0.01$).

As the lesser yam decreased in flour composition from T1 to T6 which decreased protein content of extruded products which was significantly ($p \leq 0.01$) affected. Protein nutritional value is dependent on the quality, digestibility and availability of essential amino acids. Protein digestibility value of the extrudates is higher than non extruded products. The possible cause might be the denaturation of proteins and inactivation of antinutritional factors that impair digestion (Singh *et al.*, 2007).

Table 4.13: Effect of flour composition, temperature of extrusion and the screw speed on the Protein content of the Tuber crops

extrudates.

Treatments	Flour composition (Arrowroot: Lesser Yam: Potato)	130°C			150°C			170°C		
		330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm
T1	0:50:50	4.67 ^a	3.44 ^a	3.09 ^a	4.08 ^a	3.33 ^a	2.98 ^a	3.15 ^a	2.86 ^a	2.68 ^a
T2	10:40:50	4.55 ^a	3.03 ^b	2.92 ^{ba}	3.85 ^{ba}	2.92 ^{ba}	2.68 ^{ba}	2.74 ^b	2.57 ^{ba}	2.45 ^{ba}
T3	20:30:50	4.43 ^{ba}	2.80 ^b	2.51 ^{bc}	3.50 ^b	2.86 ^b	2.39 ^{bc}	2.57 ^{cb}	2.51 ^{ba}	2.33 ^{ba}
T4	30:20:50	4.03 ^b	2.33 ^c	2.28 ^{dc}	2.68 ^c	2.16 ^c	2.04 ^{dc}	2.39 ^c	2.28 ^{bc}	2.16 ^{bc}
T5	40:10:50	2.63 ^c	2.16 ^{dc}	2.04 ^{dc}	2.45 ^{dc}	1.93 ^c	1.87 ^d	1.98 ^d	1.93 ^{dc}	1.87 ^{dc}
T6	50:0:50	2.16 ^c	1.98 ^d	1.81 ^d	2.10 ^d	1.75 ^c	1.69 ^d	1.75 ^d	1.69 ^d	1.52 ^d
SE₁		0.1067	0.0639	0.1059	0.1174	0.0968	0.0854	0.0767	0.0929	0.0850
CD₁ at 1%		0.4786	0.2864	0.4751	0.5263	0.4342	0.3831	0.3440	0.4167	0.3810
SE₂		0.0236								
CD₂ at 1%		0.0874								
SE₃		0.1000								
CD₃ at 1%		0.2771								

((‘a’-‘a’, ‘b’-‘b’, ‘c’-‘c’, ‘d’-‘d’, ‘ba’-‘ba’, ‘bc’-‘bc’, ‘dc’-‘dc’ are non significant at ($p \leq 0.01$); ‘a’-‘b’, ‘b’-‘c’, ‘c’-‘d’, ‘a’-‘ab’, ‘b’-‘ba’, ‘b’-‘bc’, ‘a’-‘ba’, ‘b’-‘ba’, ‘d’-‘dc’ are significant at ($p \leq 0.01$)). (SE₁ and CD₁ = Effect of treatment combination, individual temperature and screw speed on protein content. SE₂ and CD₂ = Effect of temperature and treatment combination on protein content. SE₃ and CD₃ = Effect of treatment combination, temperature and screw speed on protein content.)).

Table 4.14: ANOVA for Nutritional Properties of extrudates

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F_{crit}</i>
a. Protein (%)						
Treatments	15.7856121	5	3.15712	50.7718	2.85E-16	3.51384
Processing conditions	12.0652418	8	1.50816	24.2537	4.71E-13	2.99298
Error	2.48730453	40	0.06218			
Total	30.3381584	53				
b. Fat (%)						
Treatments	0.12837531	5	0.02568	167.48	1.04E-25	3.51384
Processing conditions	0.2153963	8	0.02693	175.63	1.14E-28	2.99298
Error	0.0061321	40	0.00015			
Total	0.3499037	53				
c. Fiber (%)						
Treatments	0.15654671	5	0.03131	411.92	2.84E-33	2.44947
Processing conditions	0.07716461	8	0.00965	126.902	5.95E-26	2.18017
Error	0.00304033	40	7.60E-05			
Total	0.23675165	53				
d. Ash (%)						
Treatments	1.72233025	5	0.34447	108.609	3.55E-22	3.51384
Processing conditions	0.80534815	8	0.10067	31.7406	5.55E-15	2.99298
Error	0.1268642	40	0.00317			
Total	2.65454259	53				
e. Moisture (%)						
Treatments	1.36069733	5	0.27214	103.42	8.79E-22	3.51384
Processing conditions	2.60884239	8	0.32611	123.928	9.37E-26	2.99298
Error	0.10525638	40	0.00263			
Total	4.07479609	53				
f. Carbohydrates (%)						
Treatments	40.189501	5	8.0379	125.326	2.47E-23	2.44947
Processing conditions	25.2747662	8	3.15935	49.2602	2.62E-18	2.18017
Error	2.56543339	40	0.06414			
Total	68.0297006	53				
g. Yellowness Index						
Treatments	1.48055	5	0.29611	2.69886	0.03415	2.44947
Processing conditions	2.228667	8	0.27858	2.53912	0.0245	2.18017
Error	4.388667	40	0.10972			
Total	8.097883	53				

4.4.2.2 Fat content

Table 4.15 shows the effect of flour composition, temperature of extrusion and the screw speed on the fat content (%) of the tuber crops extrudates. The fat content of extrudates varied between 1.18 and 1.51% for all treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Fat content for treatment T1 ranged from 1.35-1.51%, for T2 from 1.30-1.49%, for T3 from 1.28-1.47%, for T4 from 1.22-1.45%, for T5 from 1.21-1.41% and for T6 from 1.18-1.38% respectively. It was maximum (1.51%) at 130°C barrel temperature, screw speed is 330 rpm and feed composition level is T1 and was minimum (1.18%) at 170°C barrel temperature, screw speed is 390 rpm and feed composition level is T6. The proportion of lesser yam decreased in feed composition which may result in decreased fat content of extruded. The screw speed and temperature increased during extrusion significantly affected on the fat content of extruded. Fat content was decreased with increased temperature and screw speed of extrusion.

Table 4.15 and 4.14 (b) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the fat content of the tuber crops extrudates. It is clear from the table, fat content was significantly affected by ($p \leq 0.01$) on the flour composition, screw speed and temperature. The interaction between the flour compositions, screw speed and temperature has a significant difference on the fat content. As the properties of lesser yam decreased in flour composition from T1 to T6 which decreased fat content of extruded products which was significantly ($p \leq 0.01$) affected.

There was reduction in the fat content of the extrudate from 1.51 to 1.18 %. Extrusion cooking has been reported to aid oil extraction since oil is freed during cooking and shearing operations which break fat globules (Nelson *et al.*, 1978). The chance for lipid oxidation that significantly affect product sensory attributes and nutritional quality is reduced during extrusion. This could be attributed to high temperature that inactivates lipolytic enzymes; low residence time of the feed material in the barrel due to increase in speed and the formation of starch-lipid complex. However, air cells in expanded products and the release of pro-oxidants by screw wear favour lipid oxidation (Leszek, 2011).

4.4.2.3 Fibre content

Table 4.16 shows the effect of flour composition, temperature of extrusion and the screw speed on the fibre content (%) of the tuber crops extrudates. The fibre content of extrudates varied between 1.39 and 1.09 % for all treatments (T1 to T6), at varied temperature temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm).

Table 4.15: Effect of flour composition, temperature of extrusion and the screw speed on the Fat content of the Tuber crops

extrudates.

Treatments	Flour composition (Arrowroot: Lesser Yam: Potato)	130°C			150°C			170°C		
		330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm
T1	0:50:50	1.51 ^a	1.48 ^a	1.46 ^a	1.48 ^a	1.42 ^a	1.37 ^a	1.42 ^a	1.38 ^a	1.35 ^a
T2	10:40:50	1.49 ^{ba}	1.45 ^{ba}	1.42 ^{ba}	1.45 ^a	1.36 ^b	1.34 ^a	1.38 ^{ba}	1.32 ^{ba}	1.30 ^{ba}
T3	20:30:50	1.47 ^b	1.43 ^{bac}	1.40 ^{ba}	1.43 ^a	1.33 ^{cb}	1.30 ^b	1.35 ^{bc}	1.27 ^{ba}	1.28 ^{bc}
T4	30:20:50	1.45 ^c	1.41 ^{bac}	1.37 ^{bc}	1.39 ^a	1.30 ^{cd}	1.27 ^{cb}	1.33 ^{bc}	1.28 ^{ba}	1.22 ^{dc}
T5	40:10:50	1.41 ^d	1.39 ^{bc}	1.34 ^c	1.34 ^a	1.28 ^d	1.26 ^{cd}	1.31 ^c	1.25 ^{ba}	1.21 ^d
T6	50:0:50	1.38 ^e	1.36 ^c	1.31 ^c	1.32 ^a	1.26 ^d	1.23 ^d	1.29 ^c	1.21 ^b	1.18 ^d
SE₁		0.0046	0.0165	0.0138	0.0228	0.0100	0.0075	0.0135	0.0339	0.0136
CD₁ at 1%		0.0210	0.0739	0.0623	0.1023	0.0452	0.0340	0.0607	0.1522	0.0610
SE₂		0.0042								
CD₂ at 1%		0.0157								
SE₃		0.0179								
CD₃ at 1%		0.0497								

((‘a’-‘a’, ‘b’-‘b’, ‘c’-‘c’, ‘d’-‘d’, ‘e’-‘e’, ‘ba’-‘ba’, ‘bc’-‘bc’, ‘cb’-‘cb’, ‘dc’-‘dc’ are non significant at (p≤0.01); ‘a’-‘b’, ‘b’-‘c’, ‘c’-‘d’, ‘a’-‘ab’, ‘b’-‘ba’, ‘b’-‘bc’, ‘a’-‘ba’, ‘b’-‘ba’, ‘d’-‘dc’, ‘c’-‘cd’ are significant at (p≤0.01)). (SE₁ and CD₁ = Effect of treatment combination, individual temperature and screw speed on fat content. SE₂ and CD₂ = Effect of temperature and treatment combination on fat content. SE₃ and CD₃ = Effect of treatment combination, temperature and screw speed on fat content.)).

Table 4.16: Effect of flour composition, temperature of extrusion and the screw speed on the Fibre content of the Tuber crops

extrudates.

Treatments	Flour composition (Arrowroot: Lesser Yam: Potato)	130°C			150°C			170°C		
		330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm
T1	0:50:50	1.23 ^c	1.20 ^d	1.20 ^a	1.21 ^d	1.18 ^d	1.14 ^c	1.17 ^d	1.12 ^c	1.09 ^d
T2	10:40:50	1.27 ^c	1.25 ^c	1.23 ^a	1.23 ^{dc}	1.21 ^{dc}	1.18 ^{bc}	1.21 ^{dc}	1.18 ^{bc}	1.13 ^{dc}
T3	20:30:50	1.29 ^c	1.28 ^c	1.27 ^a	1.26 ^c	1.25 ^c	1.20 ^{bac}	1.23 ^{bac}	1.21 ^{ba}	1.17 ^{bc}
T4	30:20:50	1.33 ^{ba}	1.31 ^b	1.31 ^a	1.30 ^b	1.28 ^b	1.25 ^{bac}	1.27 ^{bac}	1.25 ^{ba}	1.20 ^{bc}
T5	40:10:50	1.35 ^a	1.34 ^{ba}	1.31 ^a	1.32 ^{ba}	1.30 ^{ba}	1.28 ^{ba}	1.30 ^{ba}	1.28 ^a	1.22 ^{ba}
T6	50:0:50	1.39 ^a	1.37 ^a	1.33 ^a	1.35 ^a	1.33 ^a	1.31 ^a	1.32 ^a	1.30 ^a	1.28 ^a
SE₁		0.0128	0.0072	0.0383	0.0088	0.0213	0.0238	0.0183	0.0196	0.0164
CD₁ at 1%		0.0578	0.0326	0.1718	0.0397	0.0956	0.1069	0.0821	0.0881	0.0737
SE₂		0.0048								
CD₂ at 1%		0.0177								
SE₃		0.0203								
CD₃ at 1%		0.0562								

((‘a’-‘a’, ‘b’-‘b’, ‘c’-‘c’, ‘d’-‘d’, ‘ba’-‘ba’, ‘bc’-‘bc’, ‘cb’-‘cb’, ‘bac’-‘bac’, ‘dc’-‘dc’ are non significant at (p≤0.01); ‘a’-‘b’, ‘b’-‘c’, ‘c’-‘d’, ‘a’-‘ab’, ‘b’-‘ba’, ‘b’-‘bc’, ‘a’-‘ba’, ‘b’-‘ba’, ‘d’-‘dc’, ‘c’-‘cd’ are significant at (p≤0.01)). (SE₁ and CD₁ = Effect of treatment combination, individual temperature and screw speed on fibre content. SE₂ and CD₂ = Effect of temperature and treatment combination on fibre content. SE₃ and CD₃ = Effect of treatment combination, temperature and screw speed on fibre content.)).

Fibre content for treatment T1 was ranges from 1.09-1.23%, for T2 from 1.13-1.27%, for T3 from 1.17-1.29%, for T4 from 1.20-1.33%, for T5 from 1.22-1.35% and for T6 from 1.28-1.39% respectively. It was maximum (1.39%) at 130°C barrel temperature, screw speed is 330 rpm and feed composition level is at T6 and was minimum (1.09%) at 170°C barrel temperature, screw speed is 390 rpm and feed composition level is T1. Table 4.16 and 4.14 (c) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the fibre content of the tuber crops extrudates. It is clear from the table, fibre content have no significant effect ($p \leq 0.01$) between the flour composition, screw speed and temperature. The interaction between the flour compositions, screw speed and temperature has a significant difference on the fibre content. As the lesser yam decreased in flour composition from T1 to T6 which increased fibre content of extruded products which was significantly ($p \leq 0.01$) affected.

As the proportion of lesser yam decreased in feed composition which may result in increased fibre content of extruded. The screw speed and temperature increased during extrusion non significantly affected on the fiber content of extruded. Fibre content was decreased with increased temperature and screw speed of extrusion. Extrusion cooking did not significantly affect the crude fibre content. As with starch, larger fragments of fibre molecules may be sheared off during extrusion (Leszek, 2011).

4.4.2.4 Ash content

Table 4.17 shows the effect of flour composition, temperature of extrusion and the screw speed on the ash content (%) of the tuber crops extrudates. The ash content of extrudates varied between 2.32 and 1.42% for all treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Ash content for treatment T1 was ranges from 1.87-2.32%, for T2 from 1.70-2.12%, for T3 from 1.65-2.07%, for T4 from 1.55-1.95%, for T5 from 1.46-1.87% and for T6 from 1.42-1.77% respectively. It was maximum (2.32%) at 170°C barrel temperature, screw speed is 390 rpm and feed composition level is T1 and was minimum (1.42%) at 130°C barrel temperature, screw speed is 330 rpm and feed composition level is T6. As the proportion of lesser yam decreased in feed composition which may result in decreased ash content of extruded. The screw speed and temperature increased during extrusion significantly affected on the ash content of extruded. Ash content increased with increased temperature and screw speed of extrusion.

Table 4.17: Effect of flour composition, temperature of extrusion and the screw speed on the Ash content of the Tuber crops

extrudates.

Treatments	Flour composition (Arrowroot: Lesser Yam: Potato)	130°C			150°C			170°C		
		330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm
T1	0:50:50	1.87 ^a	1.97 ^a	2.15 ^a	1.88 ^a	2.05 ^a	2.23 ^a	1.95 ^a	2.10 ^a	2.32 ^a
T2	10:40:50	1.70 ^b	1.88 ^{ba}	1.98 ^{ba}	1.73 ^{ba}	1.98 ^{ba}	2.02 ^b	1.88 ^{ba}	2.10 ^a	2.12 ^b
T3	20:30:50	1.65 ^b	1.75 ^{bc}	1.87 ^b	1.68 ^{bc}	1.88 ^{bc}	1.95 ^{cb}	1.80 ^{bc}	1.93 ^b	2.07 ^{cb}
T4	30:20:50	1.55 ^c	1.70 ^c	1.83 ^b	1.63 ^{bc}	1.80 ^c	1.82 ^{cd}	1.68 ^{dc}	1.85 ^{cb}	1.95 ^{cd}
T5	40:10:50	1.46 ^c	1.52 ^d	1.40 ^c	1.56 ^{dc}	1.63 ^d	1.77 ^{ed}	1.61 ^c	1.73 ^c	1.87 ^{ed}
T6	50:0:50	1.42 ^c	1.45 ^d	1.45 ^c	1.45 ^d	1.58 ^d	1.63 ^e	1.47 ^d	1.60 ^d	1.77 ^e
SE₁		0.0387	0.0314	0.0541	0.0371	0.0305	0.0348	0.0330	0.0296	0.0287
CD₁ at 1%		0.1647	0.1411	0.2428	0.1667	0.1371	0.1561	0.1483	0.1329	0.1287
SE₂		0.0089								
CD₂ at 1%		0.0329								
SE₃		0.0376								
CD₃ at 1%		0.1042								

((‘a’-‘a’, ‘b’-‘b’, ‘c’-‘c’, ‘d’-‘d’, ‘e’-‘e’, ‘ba’-‘ba’, ‘bc’-‘bc’, ‘cb’-‘cb’, ‘dc’-‘dc’, ‘ed’-‘ed’ are non significant at (p≤0.01); ‘a’-‘b’, ‘b’-‘c’, ‘c’-‘d’, ‘a’-‘ab’, ‘b’-‘ba’, ‘b’-‘bc’, ‘a’-‘ba’, ‘b’-‘ba’, ‘d’-‘dc’, ‘c’-‘cd’, ‘e’-‘ed’ are significant at (p≤0.01)). (SE₁ and CD₁ = Effect of treatment combination, individual temperature and screw speed on ash content. SE₂ and CD₂ = Effect of temperature and treatment combination on ash content. SE₃ and CD₃ = Effect of treatment combination, temperature and screw speed on ash content.)).

Table 4.17 and 4.14 (d) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the ash content of the tuber crops extrudates. It is clear from the table, ash content have a significant effect ($p \leq 0.01$) between the flour - composition, screw speed and temperature. The interaction between the flour compositions, screw speed and temperature has a significant difference in the ash content. As the lesser yam decreased in flour composition from T1 to T6 which decreased ash content of extruded products which was significantly ($p \leq 0.01$) affected.

Extrusion cooking significantly increased the ash content of the extrudates from 1.42 to 2.32 %. This could be attributed to high barrel temperature and high shear rate involved during the cooking process (James and Nwabueze, 2013). The highest ash content (2.32%) was observed for highest temperature (170°C) while lowest extrusion temperature (130°C) gave lower value for barley extrudates ash content (1.42%). The change in ash content is not much but a minute decrease is observed which is negligible (Awan *et al.*, 2010).

4.4.2.5 Moisture content

Table 4.18 shows the effect of flour composition, temperature of extrusion and the screw speed on the moisture content (%) of the tuber crops extrudates. The moisture content of extrudates varied between 6.10 and 7.40 % for all treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Moisture content for treatment T1 was ranges from 6.55-7.40%, for T2 from 6.52-7.27%, for T3 from 6.45-7.13%, for T4 from 6.35-7.08%, for T5 from 6.30-6.90% and for T6 from 6.10-6.83% respectively. It was maximum (7.40%) at 130°C barrel temperature, screw speed is 330 rpm and feed composition level is T6 and was minimum (6.10%) at 170°C barrel temperature, screw speed is 390 rpm and feed composition level is T1.

Table 4.18 and 4.14 (e) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the moisture content of the tuber crops extrudates. It is clear from the table, moisture content is significantly affected ($p \leq 0.01$) by the flour composition, screw speed and temperature. The interaction between the flour compositions, screw speed and temperature has a significant difference in the moisture content.

As the proportion of lesser yam decreased in feed composition which may result in decreased moisture content of extruded. The screw speed and temperature increased during extrusion significantly affected on the moisture content of extruded. Moisture content decreased with increased temperature and screw speed of extrusion.

Table 4.18: Effect of flour composition, temperature of extrusion and the screw speed on the Moisture content of the Tuber crops

extrudates.

Treatments	Flour composition (Arrowroot: Lesser Yam: Potato)	130°C			150°C			170°C		
		330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm
T1	0:50:50	7.40 ^a	6.90 ^a	6.80 ^a	6.92 ^a	6.80 ^a	6.60 ^a	6.67 ^a	6.68 ^a	6.55 ^a
T2	10:40:50	7.27 ^a	6.85 ^a	6.65 ^b	6.88 ^a	6.60 ^b	6.53 ^a	6.60 ^{ba}	6.55 ^b	6.52 ^a
T3	20:30:50	7.13 ^a	6.72 ^a	6.60 ^c	6.77 ^b	6.56 ^b	6.37 ^a	6.55 ^b	6.50 ^b	6.45 ^a
T4	30:20:50	7.08 ^a	6.63 ^a	6.53 ^d	6.55 ^c	6.50 ^c	6.28 ^a	6.43 ^c	6.40 ^b	6.35 ^{ba}
T5	40:10:50	6.90 ^a	6.58 ^a	6.50 ^e	6.48 ^c	6.40 ^d	6.10 ^a	6.35 ^d	6.33 ^{dc}	6.30 ^{ba}
T6	50:0:50	6.83 ^a	6.53 ^a	6.45 ^f	6.37 ^d	6.30 ^e	6.00 ^a	6.30 ^d	6.25 ^d	6.10 ^b
SE₁		0.2762	0.1929	0.0068	0.0194	0.0158	0.1559	0.0158	0.0194	0.0629
CD₁ at 1%		1.2382	0.8649	0.0305	0.0873	0.0709	0.6989	0.0709	0.0873	0.2822
SE₂		0.0352								
CD₂ at 1%		0.1306								
SE₃		0.1494								
CD₃ at 1%		0.4140								

((‘a’-‘a’, ‘b’-‘b’, ‘c’-‘c’, ‘d’-‘d’, ‘e’-‘e’, ‘f’-‘f’, ‘ba’-‘ba’, are non significant at (p≤0.01); ‘a’-‘ab’, ‘b’-‘ba’, ‘d’-‘dc’ are significant at (p≤0.01)). (SE₁ and CD₁ = Effect of treatment combination, individual temperature and screw speed on moisture content. SE₂ and CD₂ = Effect of temperature and treatment combination on moisture content. SE₃ and CD₃ = Effect of treatment combination, temperature and screw speed on moisture content.)).

4.4.2.6 Carbohydrates

Table 4.19 shows the effect of flour composition, temperature of extrusion and the screw speed on the carbohydrates (%) of the tuber crops extrudates. The carbohydrates content of extrudates varied between 83.32 and 88.16 % for all treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Carbohydrates content for treatment T1 was ranges from 86.01-83.32%, for T2 83.71-86.48%, for T3 83.98-86.70%, for T4 84.50-87.34%, for T5 86.16-87.73% and for T6 86.70-88.16% respectively. It was maximum (88.16 %) at 170°C barrel temperature, screw speed is 390 rpm and feed composition level is T1 and was minimum (83.32%) at 130°C barrel temperature, screw speed is 330 rpm and feed composition level is T6. As the proportion of lesser yam decreased in feed composition which may result in increased carbohydrates content of extruded. The screw speed and temperature increased during extrusion significantly affected on the carbohydrate content of extruded. Carbohydrates content was increased with increased temperature and screw speed of extrusion.

Table 4.19 and 4.14 (f) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the carbohydrate content of the tuber crops extrudates. It is clear from the table, carbohydrate content have a significant effect ($p \leq 0.01$) on the flour composition, screw speed and temperature. The interaction between the flour compositions, screw speed and temperature has a significant effect in the carbohydrate content. As the lesser yam decreased in flour composition from T1 to T6 which increased carbohydrate content of extruded products which was significantly ($p \leq 0.01$) affected.

Conditions that increase temperature, share and pressure tend to increase the rate of gelatinization. Complete gelatinization may not occur but, digestibility is improved on the other hand (Wang *et al.*, 1993). In essence extrusion may predigest starch depending on the composition of the feed material and operating conditions.

4.4.2.7 Yellowness Index (YI)

Table 4.20 shows the effect of flour composition, temperature of extrusion and the screw speed on the yellowness index of the tuber crops extrudates. The yellowness index of extrudates varied between 5.87 and 4.51 for all treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Yellowness index for treatment T1 was ranges from 4.79-5.86, for T2 from 4.70-5.87, for T3 from 4.53-5.83, for T4 from 4.53-5.50, for T5 from 4.54-5.53 and for T6 from 4.57-5.37 respectively. It was maximum (5.87) at 150°C barrel temperature, screw speed is 390 rpm and feed composition

Table 4.19: Effect of flour composition, temperature of extrusion and the screw speed on the Carbohydrates content of the Tuber

crops extrudates.

Treatments	Flour composition (Arrowroot: Lesser Yam: Potato)	130°C			150°C			170°C		
		330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm
T1	0:50:50	83.32 ^b	85.01 ^d	85.31 ^d	84.43 ^d	85.31 ^d	85.68 ^d	85.64 ^f	85.80 ^d	86.01 ^e
T2	10:40:50	83.71 ^b	85.53 ^{dc}	85.83 ^{cd}	84.85 ^d	86.03 ^c	86.25 ^{dc}	86.18 ^e	86.25 ^{cd}	86.48 ^{ed}
T3	20:30:50	83.98 ^b	86.02 ^{bc}	86.39 ^{cb}	85.36 ^c	86.25 ^c	86.79 ^{bc}	86.51 ^d	86.57 ^{cb}	86.70 ^{cd}
T4	30:20:50	84.50 ^b	86.61 ^{ba}	86.71 ^b	86.44 ^b	87.06 ^b	87.34 ^{ba}	86.90 ^c	86.92 ^b	87.12 ^{cb}
T5	40:10:50	86.16 ^a	86.69 ^{ba}	87.41 ^a	86.85 ^b	87.57 ^{ba}	87.73 ^a	87.44 ^b	87.45 ^a	87.54 ^b
T6	50:0:50	86.70 ^a	87.30 ^a	87.64 ^a	87.41 ^a	87.91 ^a	88.13 ^a	87.87 ^a	87.93 ^a	88.16 ^a
SE₁		0.2680	0.2122	0.1427	0.1106	0.1186	0.1982	0.0658	0.1139	0.1056
CD₁ at 1%		1.2014	0.9515	0.6398	0.4958	0.5317	0.8885	0.2952	0.5108	0.4733
SE₂		0.0415								
CD₂ at 1%		0.1540								
SE₃		0.1761								
CD₃ at 1%		0.4880								

((‘a’-‘a’, ‘b’-‘b’, ‘c’-‘c’, ‘d’-‘d’, ‘e’-‘e’, ‘f’-‘f’, ‘ba’-‘ba’, ‘bc’-‘bc’, ‘cb’-‘cb’, ‘dc’-‘dc’, ‘ed’-‘ed’ are non significant at (p≤0.01); ‘a’-‘b’, ‘b’-‘c’, ‘c’-‘d’, ‘a’-‘ab’, ‘b’-‘ba’, ‘b’-‘bc’, ‘a’ ‘ba’, ‘b’-‘ba’, ‘d’-‘dc’, ‘c’-‘cd’, ‘e’-‘ed’ are significant at (p≤0.01)). (SE₁ and CD₁ = Effect of treatment combination, individual temperature and screw speed on carbohydrate. SE₂ and CD₂ = Effect of temperature and treatment combination on carbohydrate. SE₃ and CD₃ = Effect of treatment combination, temperature and screw speed on carbohydrate.))

Table 4.20: Effect of flour composition, temperature of extrusion and the screw speed on the Yellowness Index (YI) of the Tuber crops extrudates.

Treatments	Flour composition (Arrowroot: Lesser yam: Potato)	130°C			150°C			170°C		
		330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm	330 rpm	360 rpm	390 rpm
T1	0:50:50	5.86 ^b	5.33 ^c	4.95 ^e	5.06 ^b	5.75 ^a	4.79 ^c	5.47 ^a	5.15 ^b	5.50 ^a
T2	10:40:50	5.87 ^a	4.70 ^d	4.96 ^d	5.49 ^a	5.31 ^b	4.88 ^b	5.01 ^c	4.51 ^f	4.64 ^f
T3	20:30:50	5.83 ^c	4.62 ^e	4.75 ^f	4.84 ^c	5.19 ^c	4.53 ^c	5.10 ^b	4.96 ^c	5.37 ^b
T4	30:20:50	5.31 ^d	5.50 ^b	5.05 ^c	4.53 ^f	5.50 ^d	4.89 ^a	4.75 ^e	5.19 ^a	5.03 ^c
T5	40:10:50	5.42 ^e	5.53 ^a	5.28 ^b	4.63 ^d	4.54 ^f	4.69 ^f	4.53 ^f	4.87 ^d	4.91 ^e
T6	50:00:50	4.63 ^f	4.57 ^f	5.37 ^a	4.57 ^e	4.56 ^e	4.51 ^e	4.97 ^d	4.78 ^e	4.94 ^d
SE₁		0.1368	0.1145	0.0876	0.1043	0.0956	0.0734	0.0595	0.0038	0.0021
CD₁ at 1%		0.5201	0.4321	0.1092	0.3965	0.243	0.141	0.2264	0.1987	0.1283
SE₂		0.1540								
CD₂ at 1%		0.3965								
SE₃		0.1806								
CD₃ at 1%		0.5006								

((‘a’-‘a’, ‘b’-‘b’, ‘c’-‘c’, ‘d’-‘d’, ‘e’-‘e’, ‘f’-‘f’ are non significant at ($p \leq 0.01$); ‘a’-‘b’, ‘b’-‘c’, ‘c’-‘d’, ‘d’-‘e’, ‘e’-‘f’ are significant at ($p \leq 0.01$)). (SE₁ and CD₁ = Effect of treatment combination, individual temperature and screw speed on yellowness index. SE₂ and CD₂ = Effect of temperature and treatment combination on yellowness index. SE₃ and CD₃ = Effect of treatment combination, temperature and screw speed on yellowness index.)).

level is T6 and was minimum (4.51) at 130°C barrel temperature, screw speed is 330 rpm and feed composition level is T1. Table 4.20 and 4.14 (g) shows the ANOVA for the effect of flour composition, temperature of extrusion and screw speed on the yellowness index of the tuber crops extrudates. It is clear from the table, yellowness index have a significant effect ($p \leq 0.01$) between the flour composition, screw speed and temperature. The interaction between the flour compositions, screw speed and temperature has a significant difference in the yellowness index. As the lesser yam decreased in flour composition from T1 to T6 which decreased yellowness index of extruded products which was significantly ($p \leq 0.01$) affected.

4.4.3 Sensory Evaluation

Sensory evaluation of the tuber crops extrudates shown in Table 4.21. Overall score of sensory characteristics ranged from 6.07 to 7.46 for all treatments (T1 to T6), at varied temperature of extrusion (130 to 170°C) and screw speeds (330 to 390 rpm). Increase in arrowroot proportion reduced the sensory score. Maximum acceptability was observed either at the minimum level of arrowroot proportion and vice versa. The sensory analysis of extrudates indicated that the overall acceptability of the extrudates were highest at treatment T2 (sample code 'N') at which the appearance, colour, taste, crispiness, expansion and overall acceptability was 7.5, 7.2, 8.5, 7.4, 7.0, 7.3 and 7.5 respectively. The treatment at which the flour composition at which Arrowroot:Lesser yam:Potato (10:40:50) at extrusion temperature 130°C and screw speed at the extrusion was 390 rpm. Table 4.22 shows the ANOVA for the sensory analysis of the scores obtained for extrudates at each treatment combinations.

Table 4.21: Sensory Evaluation of Tuber of the Tuber crops extrudates

Sample Code	Flour composition (Arrowroot: Lesser Yam: Potato)	Temperature, °C	RPM of Screw	Sensory Parameters						
				Appearance	Colour	Taste	Texture	Crispiness	Expansion	Overall Acceptability
A	0:50:50	130	330	6.5	6.4	6.1	6.5	6.6	6.6	6.5
B	10:40:50	130	330	6.1	6.1	6.2	6.2	6.4	6.5	6.3
C	20:30:50	130	330	6.4	6.3	6.3	6.4	6.6	6.7	6.5
D	30:20:50	130	330	6.5	6.5	6.6	6.5	6.5	6.4	6.5
E	40:10:50	130	330	6.1	6.2	6.4	6.3	6.3	6.4	6.3
F	50:0:50	130	330	6.4	6.4	6.3	6.3	6.4	6.2	6.3

Sample Code	Flour composition (Arrowroot: Lesser Yam: Potato)	Temperature, °C	RPM of Screw	Sensory Parameters						
				Appearance	Colour	Taste	Texture	Crispiness	Expansion	Overall Acceptability
G	0:50:50	130	360	6.4	6.1	6.0	6.2	6.1	6.2	6.2
H	10:40:50	130	360	6.5	6.2	6.1	6.3	6.3	6.3	6.3
I	20:30:50	130	360	7.5	7.5	6.9	7.4	7.1	7.0	7.2
J	30:20:50	130	360	7.5	7.4	6.7	7.4	6.8	6.5	7.0
K	40:10:50	130	360	6.5	7.5	7.3	7.1	7.4	7.4	7.2
L	50:0:50	130	360	7.6	7.4	7.2	7.5	7.1	7.3	7.4
M	0:50:50	130	390	7.3	7.7	7.4	7.3	7.3	7.4	7.4
N	10:40:50	130	390	7.5	7.2	8.5	7.4	7.0	7.3	7.5
O	20:30:50	130	390	7.3	7.6	7.4	7.4	7.2	7.3	7.4
P	30:20:50	130	390	6.9	7.5	7.0	7.3	7.5	7.5	7.3
Q	40:10:50	130	390	7.5	7.5	7.0	7.6	7.0	7.1	7.3
R	50:0:50	130	390	7.1	7.5	7.4	7.2	7.4	7.5	7.3
S	0:50:50	150	330	5.8	5.6	6.3	8.0	6.5	6.4	6.4
T	10:40:50	150	330	6.2	5.7	6.1	6.3	5.7	6.4	6.1
U	20:30:50	150	330	5.9	6.1	6.0	6.5	7.3	6.8	6.4
V	30:20:50	150	330	6.0	6.5	7.0	6.7	6.4	7.3	6.7
W	40:10:50	150	330	5.6	5.9	6.1	8.0	6.4	6.8	6.5
X	50:0:50	150	330	6.1	6.6	7.3	6.8	6.6	7.0	6.7
Y	0:50:50	150	360	5.8	5.9	6.2	6.2	6.7	6.9	6.3
Z	10:40:50	150	360	6.0	6.3	6.5	6.6	7.0	7.3	6.6
A1	20:30:50	150	360	6.5	6.2	6.5	6.5	6.4	6.2	6.4
B1	30:20:50	150	360	7.0	6.7	6.8	6.6	6.7	6.8	6.8
C1	40:10:50	150	360	5.3	5.8	6.2	6.5	6.4	6.6	6.1
D1	50:0:50	150	360	5.4	5.9	6.5	6.6	6.5	5.6	6.1
E1	0:50:50	150	390	7.1	7.8	6.8	7.3	6.9	7.3	7.2
F1	10:40:50	150	390	7.4	7.4	6.7	7.5	7.0	7.0	7.2
G1	20:30:50	150	390	6.9	7.4	6.8	6.9	7.3	7.5	7.1
H1	30:20:50	150	390	6.7	6.3	7.4	7.3	7.1	7.0	6.9
I1	40:10:50	150	390	6.8	6.3	7.3	7.1	7.0	7.0	7.0
J1	50:0:50	150	390	6.7	6.2	7.2	7.0	7.0	7.0	6.9
K1	0:50:50	170	330	6.2	5.7	5.8	6.3	6.6	6.6	6.2
L1	10:40:50	170	330	6.2	6.3	7.7	6.4	6.2	6.4	6.5
M1	20:30:50	170	330	6.7	6.6	6.4	6.5	6.5	6.4	6.5
N1	30:20:50	170	330	6.9	6.7	6.5	6.7	6.5	6.6	6.6

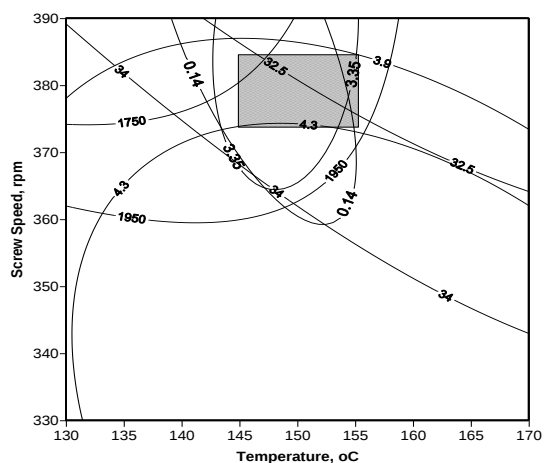
Sample Code	Flour composition (Arrowroot: Lesser Yam: Potato)	Temperature, °C	RPM of Screw	Sensory Parameters						
				Appearance	Colour	Taste	Texture	Crispiness	Expansion	Overall Acceptability
O1	40:10:50	170	330	6.7	6.5	6.4	6.5	6.7	6.5	6.6
P1	50:0:50	170	330	6.4	6.2	6.2	6.2	6.1	6.5	6.3
Q1	0:50:50	170	360	7.0	6.0	6.5	6.6	7.0	6.9	6.7
R1	10:40:50	170	360	6.5	6.5	6.8	6.7	6.4	6.8	6.6
S1	20:30:50	170	360	5.7	6.4	6.4	6.7	5.9	6.7	6.3
T1	30:20:50	170	360	6.6	6.5	5.7	6.8	7.7	7.4	6.8
U1	40:10:50	170	360	5.7	5.9	6.5	6.2	6.5	6.9	6.3
V1	50:0:50	170	360	6.5	6.1	6.5	6.7	6.5	7.0	6.5
W1	0:50:50	170	390	6.5	8.3	7.2	7.3	6.6	7.4	7.2
X1	10:40:50	170	390	6.0	6.5	6.5	6.8	7.0	7.1	6.6
Y1	20:30:50	170	390	6.1	6.3	6.5	6.5	6.8	7.0	6.6
Z1	30:20:50	170	390	6.0	5.9	6.4	7.0	7.3	7.4	6.7
A11	40:10:50	170	390	7.5	7.2	6.7	7.4	6.9	7.2	7.1
B11	50:0:50	170	390	7.5	7.3	6.7	7.4	6.9	7.0	7.1
C11	CONTROL			7.2	6.9	6.8	7.1	6.9	6.4	6.9

Table 4.22: ANOVA for the sensory analysis of the scores obtained for extrudates at each treatment combinations.

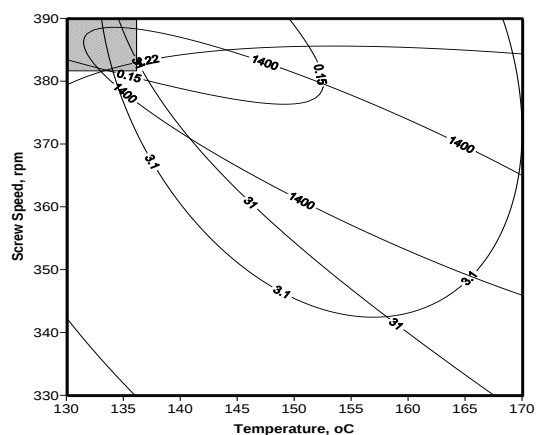
Source of Variation	SS	Df	MS	F	P-value	F _{crit}
Rows	61.56902	53	1.16168	10.35588	7.05E-44	1.380984
Columns	4.336667	6	0.722778	6.443259	2E-06	2.127128
Error	35.6719	318	0.112176			
Total	101.5776	377				

4.4.4 Optimization processing conditions of extrudates

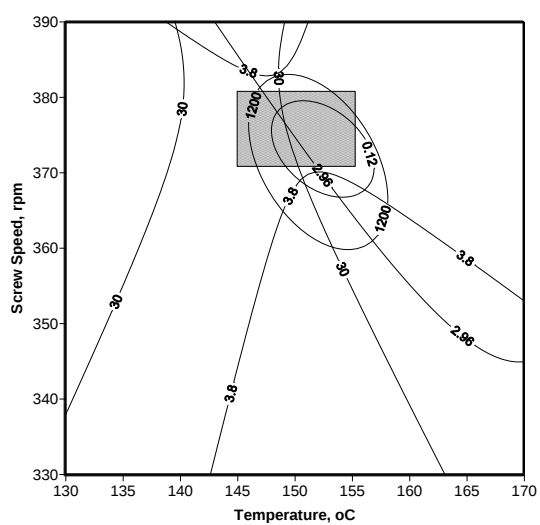
The extrudates were optimized based on its desirable functional properties like lower bulk density, more expansion ratio, lower hardness, higher water absorption index, higher water solubility index. Fig. 4.18 (a)-(f) shows the treatment wise optimum zone properties of



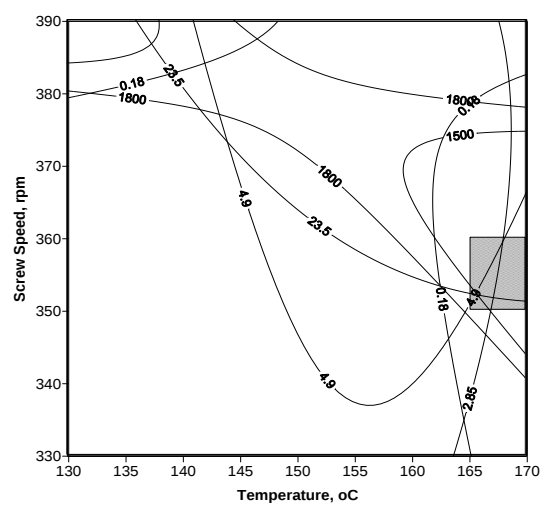
(a) Optimum zone for the Treatment T1



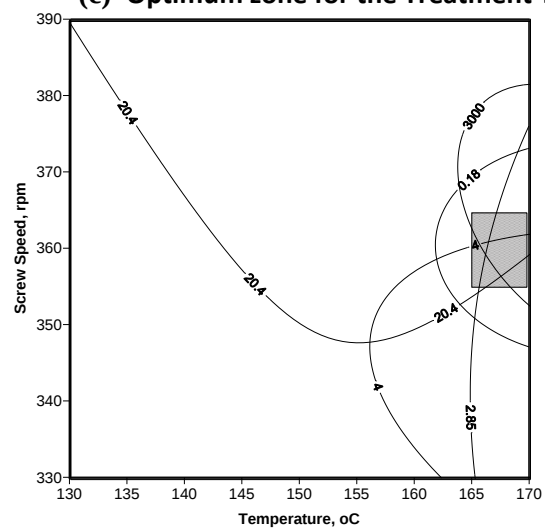
(b) Optimum zone for the Treatment T2



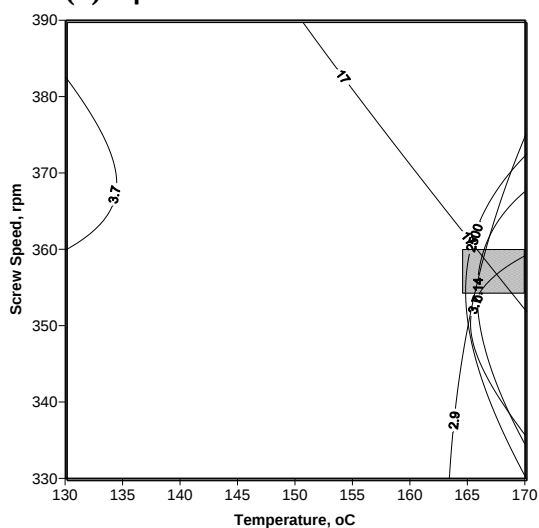
(c) Optimum zone for the Treatment T3



(d) Optimum zone for the Treatment T4



(e) Optimum zone for the Treatment T5



(f) Optimum zone for the Treatment T6

Fig. 4.18: Optimum zone Treatments wise

these extrudates prepared for treatments T1, T2, T3, T4, T5 and T6 respectively at extrusion temperature 130 to 170°C and screw speed 330 to 390 rpm. Fig. 4.19 (a) to (c) shows the properties of optimum zone product for functional, nutritional and sensory properties of extrudates. Table 4.23 and 4.24 shows the treatment wise optimum zone for functional and nutritional properties of tuber crop extrudates respectively.

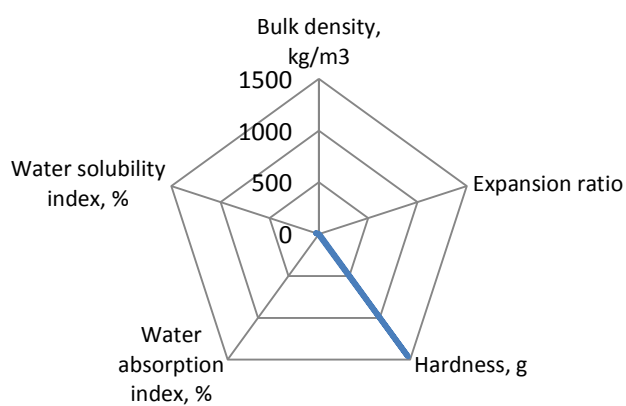
Table 4.23: Treatment wise optimum zone of lower bulk density, more expansion ratio, lower Hardness, higher water absorption capacity, higher water solubility index

Treatments	Optimum Temperature, °C	Optimum RPM	Bulk Density, g/cc	Expansion ratio	Hardness, g	Water Absorption capacity (%)	Water Solubility index (%)
T1	145-155	375-385	0.14	3.35	1710-1870	3.89-4.2	32.5 -33.7
T2	130-135	385-390	0.15	3.06-3.13	1420-1500	4.22	31.0-31.6
T3	145-155	370-380	0.12-0.13	2.88-3.01	1200-1310	3.8-3.92	29.10-30.0
T4	165-170	370-380	0.18	2.75-2.85	1500-1800	4.75-5.03	22.8-23.9
T5	165-170	355-365	0.18	2.79-2.9	3000-3300	3.9-4.07	11.6-20.8
T6	165-170	355-365	0.13-0.16	2.81-3.00	2300-2800	3.68-3.78	16.7-17.5

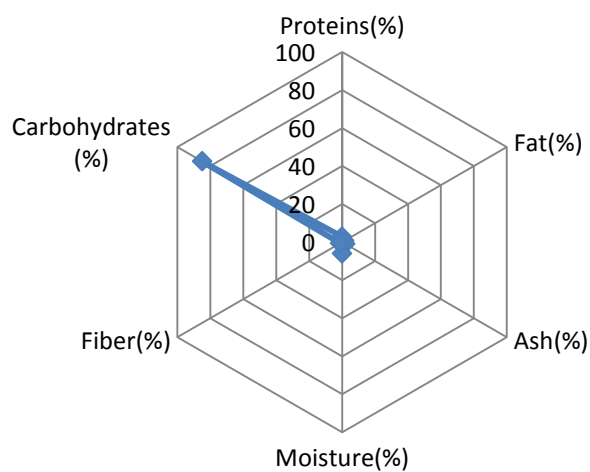
Table 4.24: Treatment wise optimum zone for nutritional properties

Treatments	Optimum Temperature, °C	Optimum RPM	Proteins %	Fat, %	Ash,%	Moisture , %	Carbohydrates, %	Fibers, %
T1	145-155	375-385	2.98-3.81	1.38-1.41	2.11-2.22	6.50-6.72	85.65-85.68	1.13-1.14
T2	130-135	385-390	2.80-2.81	1.40-1.42	1.96-1.98	6.0-6.70	85.01-85.23	1.20-1.21
T3	145-155	370-380	2.48-2.67	1.32-1.34	1.88-1.95	6.38-6.52	86.24-86.12	1.21-1.24
T4	165-170	370-380	2.0-2.1	1.27-1.30	1.79-1.85	6.35-6.39	87.72-87.34	1.24-1.25
T5	165-170	355-365	1.85-1.90	1.24-1.26	1.72-1.77	6.25-6.33	87.44-87.45	1.27-1.29
T6	165-170	355-365	1.64-1.72	1.22-1.25	1.58-1.59	6.20-6.25	87.89-87.92	1.30-1.31

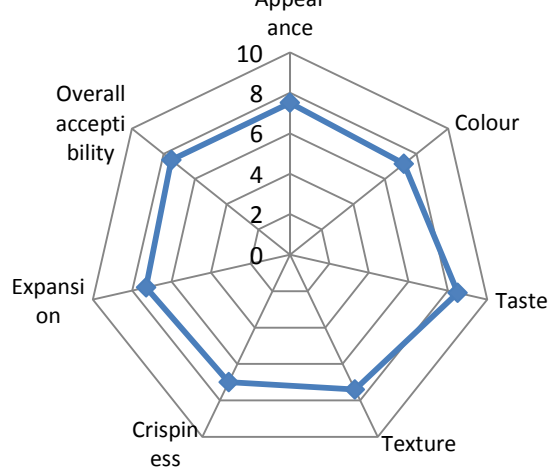
The optimum zones for treatment T1, T2, T3, T4, T5 and T6 are observed at extrusion temperature and screw speeds i.e. 145-155°C, 375-385 rpm; 130-135°C, 380-390 rpm; 145-155°C, 370-380 rpm; 165-170°C, 370-380 rpm; 165-170°C, 355-365 rpm and 165-170°C, 355-365 rpm respectively. Table 4.23 shows the functional properties of optimum zone. Table 4.24 shows that the nutritional properties at the optimum zone at T1, T2, T3, T4, T5 and T6. The optimum product has best retention of functional properties, nutritional properties and highest sensory scores. Comparing Table 4.23, 4.24 and 4.21 the treatment T2 at which the product has best functional properties i.e. bulk density, expansion ratio, hardness, water absorption index and water solubility index are 0.15 g/cm³, 3.13, 1460 g, 4.22 %, 31.3 % respectively. The nutritional properties of extrudates at the optimum products were protein 2.8 %, fat 1.40 %, ash 1.96 %, moisture 6.0 %, fiber 1.20 % and carbohydrate 85.01 % respectively. The treatment T2 receives a highest sensory score i.e. higher overall



(a) Functional properties



(b) Nutritional properties



(c) Sensory evaluation

Fig. 4.19: Properties of optimum products (a) Functional properties; (b) Nutritional properties and (c) Sensory evaluation.

acceptability i.e. 7.5 (appearance, colour, taste, texture, crispiness, expansion, overall acceptability were 7.5, 7.2, 8.5, 7.4, 7.0, 7.3 and 7.5 respectively.

4.5 Packaging and storage of extrudates

Aluminium foil pouch, polyethylene pouch and polyester pouch are used for packaging study. They stored at room temperature for 60 days. Determine the functional and physical properties of stored sample of treatment T2 (Arrowroot: Lesser yam: potato i.e. 10:40:50)

4.5.1 Nutritional properties of stored sample

The nutritional properties of stored sample include the protein, fat, fiber, ash, moisture and carbohydrates.

4.5.1.1 Protein content

Table 4.25 shows the effect of packaging material and storage duration on protein content of extrudates. The protein content decreased from 2.92 to 2.70 %, 2.92 to 2.46 % and 2.92 to 2.57 % in aluminium foil pouch, polyethylene pouch and polyester pouch respectively. Table 4.26 (a) shows the ANOVA for change in protein content in 60 days storage duration for arrowroot, lesser yam and potato based extrudates.

Decrease in protein content with increase in storage period from 0-60 days is higher in polyethylene pouch than polyester pouch and aluminium foil pouch for extruded. This decrease in protein content with increase in storage duration was not significant effect at $p \leq 0.01$ for extrudates. The effect of packaging materials and storage durations on the protein content of the extrudates were non significant at $p \leq 0.01$. As the difference between means of protein content of extrudates at all the interval for polyethylene pouch, polyester pouch and aluminium foil pouch was higher than CD and has non significant effect at $p \leq 0.01$ from each other.

Table 4.25: Effect of packaging material and storage duration on Protein content of extrudates.

Sr. No.	Packaging material	0	10	20	30	40	50	60
1	Aluminium foil pouch	2.92 ^a	2.87 ^a	2.84 ^a	2.81 ^a	2.75 ^a	2.70 ^a	2.70 ^a
2	Polyethylene pouch	2.92 ^a	2.81 ^a	2.75 ^a	2.63 ^{ba}	2.57 ^a	2.52 ^a	2.46 ^{ba}
3	Polyester pouch	2.92 ^a	2.83 ^a	2.82 ^a	2.78 ^b	2.64 ^a	2.60 ^a	2.57 ^b
SE		0.0262	0.0698	0.0804	0.0340	0.0698	0.0594	0.0348
CD at 1%		0.1176	0.3127	0.3603	0.1523	0.3128	0.2661	0.1561

(Same letter are not significantly different ($p \leq 0.01$))

Table 4.26: ANOVA for Nutritional properties of storage study.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
a. Protein (%)						
Storage durations	0.29236	6	0.04873	7.88341	0.00075	4.45582
Packaging materials	0.08653	14	0.00618			
Total	0.3789	20				
b. Fat (%)						
Storage durations	0.12579	6	0.02097	31.4476	2.4E-07	4.45582
Packaging materials	0.00933	14	0.00067			
Total	0.13512	20				
c. Fiber (%)						
Storage durations	0.08118	6	0.01353	37.8844	7.2E-08	4.45582
Packaging materials	0.005	14	0.00036			
Total	0.08618	20				
d. Ash Content (%)						
Storage durations	0.08183	6	0.01364	24.9043	1E-06	4.45582
Packaging materials	0.00767	14	0.00055			
Total	0.0895	20				
e. Moisture content (%)						
Storage durations	0.1014	6	0.0169	33.8431	1.5E-07	4.45582
Packaging materials	0.00699	14	0.0005			
Total	0.10839	20				
f. Carbohydrates (%)						
Storage durations	1.01945	6	0.16991	5.12381	0.00559	4.45582
Packaging materials	0.46425	14	0.03316			
Total	1.4837	20				

4.5.1.2 Fat content

The fat content decreased from 1.42 to 1.22 %, 1.42 to 1.15 % and 1.42 to 1.19 % in aluminium foil pouch, polyethylene pouch and polyester pouch respectively. Table 4.27 shows the effect of packaging material and storage duration on fat content of extrudates. Table 4.26 (b) shows the ANOVA for change in fat content in 60 days storage duration for arrowroot, lesser yam and potato based extrudates.

Decrease in fat content with increase in storage period from 0-60 days is higher in polyethylene pouch than polyester pouch and aluminium foil pouch for extruded. This decrease in fat content with increase in storage duration was non significant effect at $p \leq 0.01$ for extrudates. The effect of packaging materials and storage durations on the fat content of

the extrudates was non significant effect at $p \leq 0.01$. As the difference between the means of fat contents of extrudates at all the interval for polyethylene pouch, polyester pouch and aluminium foil pouch was higher than CD and has non significant effect at $p \leq 0.01$ from each other.

The decrease in fat content in extruded snack may be attributed to the development of rancidity as a result of lipids hydrolysis that occurs during storage. The fat deterioration during storage may be attributed to activity of lipase enzyme which split off the fat into free fatty acids and glycerol in the presence of catalyst like moisture, light and heat. The main reason of decreasing fat content is oxidation of fat into fatty acids simultaneously with the time of storage (Saurabh *et al.*, 2013). Fat content decreased with increase in storage durations. Similar findings were reported by Osundahunsi, 2006; Balfour *et al.*, 2014; Saurabh *et al.*, 2013, for extruded from soya bean with paintain flour blends, extruded fortified corn and snack food respectively.

A decrease in fat content was also observed in all the packaging material with the increase in storage period from 0-60 days with non significant effect at $p \leq 0.01$.

Table 4.27: Effect of packaging material and storage duration on Fat content of extrudates.

Sr. No.	Packaging material	0	10	20	30	40	50	60
1	Aluminium foil pouch	1.42 ^a	1.41 ^a	1.39 ^a	1.35 ^a	1.33 ^a	1.29 ^a	1.22 ^a
2	Polyethylene pouch	1.42 ^a	1.39 ^{ba}	1.36 ^a	1.33 ^a	1.26 ^a	1.21 ^a	1.15 ^a
3	Polyester pouch	1.42 ^a	1.40 ^b	1.37 ^a	1.35 ^a	1.3 ^a	1.27 ^a	1.19 ^a
SE		0.0000	0.0046	0.0347	0.0150	0.0235	0.0263	0.0464
CD at 1%		0.0000	0.0208	0.1555	0.0674	0.1051	0.118	0.2081

(Same letter are not significantly different ($p \leq 0.01$))

4.5.1.3 Fiber content

The fiber content decreased from 1.23 to 1.06 %, 1.23 to 1.03 % and 1.23 to 1.05 % in aluminium foil pouch, polyethylene pouch and polyester pouch respectively. Table 4.28 shows the effect of packaging material and storage duration on fiber content of extrudates. Table 4.26 (c) shows the ANOVA for change in fiber content in 60 days storage duration for arrowroot, lesser yam and potato based extrudates. Decrease in fiber content with increase in storage period from 0-60 days is higher in polyethylene pouch than polyester pouch and aluminium foil pouch for extruded. This decrease in fiber content with increase in storage duration was non significant effect at $p \leq 0.01$ for extrudates. The effect of packaging materials

and storage durations on the fiber content of the extrudates was non significant effect at $p \leq 0.01$. As the difference between the means of fiber contents of extrudates at all the interval for polyethylene pouch, polyester pouch and aluminium foil pouch was higher than CD and has non significant difference at $p \leq 0.01$ from each other.

Fiber content decreased with increase in storage durations. Similar findings were reported by Bhattacharya and Prakash, 1994; Balfour *et al.*, 2014 for extruded from rice and chick pea flour and extruded fortified corn respectively.

A decrease in fiber content was also observed in all the packaging material with the increase in storage period from 0-60 days with significant effect at $p \leq 0.01$.

Table 4.28: Effect of packaging material and storage duration on Fibre content of extrudates.

Sr. No.	Packaging material	0	10	20	30	40	50	60
1	Aluminium foil pouch	1.23 ^a	1.23 ^a	1.21 ^a	1.18 ^a	1.16 ^a	1.11 ^a	1.06 ^a
2	Polyethylene pouch	1.23 ^a	1.21 ^a	1.17 ^a	1.14 ^a	1.11 ^{ba}	1.06 ^a	1.03 ^a
3	Polyester pouch	1.23 ^a	1.21 ^a	1.19 ^a	1.16 ^a	1.13 ^b	1.10 ^a	1.05 ^a
SE		0.0000	0.0109	0.0118	0.0178	0.0095	0.0167	0.0279
CD at 1%		0.0000	0.0489	0.0529	0.0798	0.0428	0.0749	0.1251

(Same letter are not significantly different ($p \leq 0.01$))

4.5.1.4 Ash content

The ash content decreased from 1.99 to 1.83 %, 1.99 to 1.77 % and 1.99 to 1.81 % in aluminium foil pouch, polyethylene pouch and polyester pouch respectively. Table 4.29 shows the effect of packaging material and storage duration on ash content of extrudates.. Table 4.26 (d) shows the ANOVA for change in ash content in 60 days storage duration for arrowroot, lesser yam and potato based extrudates.

Decrease in ash content with increase in storage period from 0-60 days is higher in polyethylene pouch than polyester pouch and aluminium foil pouch for extruded. This decrease in ash content with increase in storage duration was non significant at $p \leq 0.01$ for extrudates. The effect of packaging materials and storage durations on the ash content of the extrudates was non significant at $p \leq 0.01$. As the difference between the means of ash contents of extrudates at all the interval for polyethylene pouch, polyester pouch and aluminium foil pouch was higher than CD and has non significant difference at $p \leq 0.01$.

Ash content decreased with increase in storage durations. Similar findings were reported by Balfour *et al.*, 2014 for extruded from rice and chick pea flour and extruded fortified corn respectively.

A decrease in ash content was also observed in all the packaging material with the increase in storage period from 0-60 days non significant at $p \leq 0.01$.

Table 4.29: Effect of packaging material and storage duration on Ash content of extrudates.

Sr. No.	Packaging material	0	10	20	30	40	50	60
1	Aluminium foil pouch	1.99 ^a	1.98 ^a	1.96 ^a	1.93 ^a	1.91 ^a	1.87 ^a	1.83 ^a
2	Polyethylene pouch	1.99 ^a	1.95 ^a	1.92 ^a	1.89 ^a	1.85 ^{ba}	1.81 ^a	1.77 ^a
3	Polyester pouch	1.99 ^a	1.96 ^a	1.95 ^a	1.90 ^a	1.88 ^b	1.84 ^a	1.81 ^a
SE		0.0000	0.0089	0.0182	0.0128	0.0114	0.0149	0.0226
CD at 1%		0.0000	0.0399	0.0815	0.0573	0.0512	0.0667	0.1015

(Same letter are not significantly different ($p \leq 0.01$))

4.5.1.5 Moisture content

The effect of packaging material and storage period on the moisture content of extrudates. Table 4.30 shows the effect of packaging material and storage duration on moisture content of extrudates. The moisture content increased from 6.65 to 6.83 %, 6.65 to 6.84 % and 6.65 to 6.87 % in aluminium foil pouch, polyethylene pouch and polyester pouch respectively. Table 4.26 (e) shows the ANOVA for change in moisture content in 60 days storage duration for arrowroot, lesser yam and potato based extrudates.

Increase in moisture content with increase in storage period from 0-60 days is higher in polyester pouch followed by polyethylene pouch and aluminium foil pouch for extruded. This increase in moisture content with increase in storage duration was no significant at $p \leq 0.01$ for extrudates. The effect of packaging materials and storage durations on the moisture content of the extrudates were non significant at $p \leq 0.01$. As the difference between the means of moisture contents of extrudates at all the interval for polyethylene pouch, polyester pouch and aluminium foil pouch was higher than CD and has non significant difference at $p \leq 0.01$ from each other.

Moisture content increased with increase in storage durations. Similar findings were reported by Akhtar *et al.*, 2008; Elleuch *et al.*, 2011; Balfour *et al.*, 2014 for extruded from whole wheat flour, dietary fiber and fiber rich products and extruded fortified corn respectively.

A increase in moisture content was also observed in all the packaging material with the increase in storage period from 0-60 days non significant at $p \leq 0.01$.

Table 4.30: Effect of packaging material and storage duration on Moisture content of extrudates.

Sr. No.	Packaging material	0	10	20	30	40	50	60
1	Aluminium foil pouch	6.65 ^a	6.69 ^a	6.68 ^a	6.69 ^a	6.73 ^b	6.80 ^a	6.83 ^a
2	Polyethylene pouch	6.65 ^a	6.67 ^a	6.69 ^a	6.72 ^a	6.79 ^{ba}	6.82 ^a	6.84 ^a
3	Polyester pouch	6.65 ^a	6.67 ^a	6.71 ^a	6.75 ^a	6.80 ^a	6.84 ^a	6.87 ^a
SE		0.0000	0.0098	0.0232	0.0415	0.0153	0.0234	0.0349
CD at 1%		0.0000	0.0442	0.1039	0.186	0.0684	0.105	0.1566

(Same letter are not significantly different ($p \leq 0.01$))

4.5.1.6 Carbohydrates

The carbohydrate increased from 85.80 to 86.01 %, 85.80 to 86.22 % and 85.75 to 86.73 % in aluminium foil pouch, polyethylene pouch and polyester pouch respectively. Table 4.31 shows the effect of packaging material and storage duration on carbohydrate of extrudates. Table 4.26 (f) shows the ANOVA for change in carbohydrate in 60 days storage duration for arrowroot, lesser yam and potato based extrudates.

Increase in carbohydrate with increase in storage period from 0-60 days is higher in polyethylene pouch pouches followed by polyester pouch and aluminium foil pouch for extruded. This increase in carbohydrate with increase in storage duration was no significant at $p \leq 0.01$ for extrudates. The effect of packaging materials and storage durations on the carbohydrates content of the extrudates were non significant at $p \leq 0.01$. As the difference between the means of carbohydrate of extrudates at the entire interval for polyethylene pouch, polyester pouch and aluminium foil pouch was higher than CD and has non significant different at $p \leq 0.01$.

Carbohydrate increased with increase in storage durations. Similar findings were reported by Sumathi *et al.*, 2007; Balfour *et al.*, 2014 for extruded from pearl millet and extruded fortified corn respectively. A increase in carbohydrate was also observed in all the packaging material with the increase in storage period from 0-60 days non significant effect at $p \leq 0.01$.

Table 4.31: Effect of packaging material and storage duration on Carbohydrate of extrudates.

Sr. No.	Packaging material	0	10	20	30	40	50	60
1	Aluminium foil pouch	85.80 ^a	85.87 ^a	85.95 ^a	86.06 ^b	86.05 ^a	86.23 ^a	86.01 ^b
2	Polyethylene pouch	85.80 ^a	85.92 ^a	86.00 ^a	86.12 ^{ba}	86.11 ^a	86.38 ^a	86.55 ^a
3	Polyester pouch	85.75 ^a	85.98 ^a	86.10 ^a	86.28 ^a	86.42 ^a	86.57 ^a	86.73 ^a
SE		0.0207	0.0472	0.0970	0.0394	0.0861	0.0762	0.0712
CD at 1%		0.0927	0.2116	0.4348	0.1765	0.3861	0.3415	0.3191

(Same letter are not significantly different ($p \leq 0.01$))

4.5.2 Functional properties of stored sample

The functional properties of stored sample extrudates include the expansion ratio, bulk density, water absorption index, water solubility index and hardness of extrudates

4.5.2.1 Expansion ratio (ER)

The effect of packaging material and storage period on the expansion ratio of extruded prepared with arrowroot (10%), lesser yam (40%) and potato (50%) is presented in Table 4.32.

Table 4.32 shows the effect of packaging material and storage duration on expansion ratio of extrudates. The expansion ratio increased from 3.06 to 3.10, 3.06 to 3.09 and 3.06 to 3.09 in aluminium foil pouch, polyethylene pouch and polyester pouch respectively with 60 days of storage period. Table 4.33 (a) shows the ANOVA for change in expansion ratio in 60 days storage duration for arrowroot, lesser yam and potato based extrudates. The expansion ratio with storage duration has non significant at $p \leq 0.01$ for extrudates. Expansion ratio does not change with increase in storage durations the packaging material at $p \leq 0.01$.

Table 4.32: Effect of packaging material and storage duration on Expansion ratio of extrudates.

Sr. No.	Packaging material	0	10	20	30	40	50	60
1	Aluminium foil pouch	3.06 ^a	3.09 ^a	3.10 ^a	3.06 ^a	3.08 ^a	3.08 ^a	3.09 ^a
2	Polyethylene pouch	3.06 ^a	3.08 ^b	3.09 ^a	3.06 ^a	3.09 ^a	3.07 ^a	3.09 ^a
3	Polyester pouch	3.06 ^a	3.06 ^{ba}	3.07 ^a	3.08 ^a	3.08 ^a	3.09 ^a	3.06 ^a
SE		0.0001	0.0087	0.0049	0.0068	0.0049	0.0042	0.0051
CD at 1%		0.0004	0.0388	0.0222	0.0304	0.0218	0.0189	0.0228

(Same letter are not significantly different ($p \leq 0.01$))

Table 4.33: ANOVA for Functional properties of storage study.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
a. Expansion ratio						
Storage durations	0.00163	6	0.00027	1.83871	0.163	4.45582
Packaging materials	0.00207	14	0.00015			
Total	0.0037	20				
b. Bulk density (g/cm³)						
Storage durations	0.01645	6	0.00274	22.141	2.2E-06	4.45582
Packaging materials	0.00173	14	0.00012			
Total	0.01818	20				
c. Water Absorption Index (g/g)						
Storage durations	0.21591	6	0.03599	44.716	2.4E-08	4.45582
Packaging materials	0.01127	14	0.0008			
Total	0.22718	20				
d. Water Solubility Index (%)						
Storage durations	350.975	6	58.4958	84.8802	3.4E-10	4.45582
Packaging materials	9.6482	14	0.68916			
Total	360.623	20				
e. Hardness (g)						
Storage durations	195426	6	32571	34.211	1.4E-07	4.45582
Packaging materials	13328.9	14	952.062			
Total	208755	20				

4.5.2.2 Bulk density (BD)

The effect of packaging material and storage period on the bulk density of extruded prepared with arrowroot (10%), lesser yam (40%) and potato (50%) is presented in Table 4.34. Table 4.34 shows the effect of packaging material and storage duration on bulk density of extrudates. The bulk density ranges from 0.18 to 0.09 g/cm³, 0.17 to 0.08 g/cm³, 0.18 to 0.10 g/cm³ in aluminium foil pouch, polyethylene pouch and polyester pouch respectively. Table 4.33 (b) shows the ANOVA for change in bulk density in 60 days storage duration for arrowroot, lesser yam and potato based extrudates.

Decrease in bulk density with increase in storage period from 0-60 days is higher in polyethylene pouch than polyester pouch and aluminium foil pouch for extruded. This decrease in bulk density with increase in storage duration has non significant at $p \leq 0.01$ for extrudates. The effect of packaging materials and storage durations on the bulk density of the extrudates were non significant at $p \leq 0.01$. As the difference between the means of bulk density of extrudates at all the interval for polyethylene pouch, polyester pouch and aluminium foil pouch was higher than CD and has non significant difference at $p \leq 0.01$ from each other.

Bulk density increased with increase in storage durations. Similar findings were reported by Sumathi *et al.*, 2007; Balfour *et al.*, 2014 for extruded from pearl millet and extruded fortified corn respectively.

A increase in bulk density was also observed in all the packaging material with the increase in storage period from 0-60 days non significant at $p \leq 0.01$.

Table 4.34: Effect of packaging material and storage duration on Bulk density of extrudates.

Sr. No.	Packaging material	0	10	20	30	40	50	60
1	Aluminium foil pouch	0.18 ^a	0.16 ^a	0.16 ^a	0.14 ^a	0.13 ^a	0.11 ^{ba}	0.09 ^a
2	Polyethylene pouch	0.17 ^a	0.15 ^{ba}	0.13 ^a	0.12 ^a	0.10 ^a	0.09 ^a	0.08 ^b
3	Polyester pouch	0.18 ^a	0.15 ^b	0.15 ^a	0.13 ^a	0.12 ^b	0.11 ^b	0.10 ^a
SE		0.0004	0.0033	0.0055	0.0076	0.0019	0.0092	0.0073
CD at 1%		0.0017	0.0149	0.0247	0.0341	0.0086	0.0412	0.0327

(Same letter are not significantly different ($p \leq 0.01$))

4.5.2.3 Water Absorption Index (WAI)

The effect of packaging material and storage period on the water absorption index of extruded proportions of arrowroot (10%), lesser yam (40%) and potato (50%) is presented in Table 4.35.

Table 4.35 shows the effect of packaging material and storage duration on water absorption index of extrudates. The water absorption index increased from 4.27 to 4.54 g/g, 4.27 to 4.59 g/g and 4.27 to 4.57 g/g in aluminium foil pouch, polyethylene pouch and polyester pouch respectively. Table 4.33 (c) shows the ANOVA for change in water absorption index in 60 days storage duration for arrowroot, lesser yam and potato based extrudates.

Increase in water absorption index with increase in storage period from 0-60 days is higher in polyethylene pouch than polyester pouch and aluminium foil pouch for extruded. This increase in water absorption index with increase in storage duration was non significant at $p \leq 0.01$ for extrudates. The effect of packaging materials and storage durations on the water absorption index of the extrudates were non significant at $p \leq 0.01$. As the difference between the means of water absorption index of extrudates at all the interval for polyethylene pouch, polyester pouch and aluminium foil pouch was higher than CD and has non significant difference at $p \leq 0.01$.

Water absorption index increased with increase in storage durations. Similar findings were reported by Rocha-Guzma'n *et al.*, 2006 for common bean extrusion. Increase in water absorption index was also observed in all the packaging material with the increase in storage period from 0-60 days (non significant at $p \leq 0.01$). It is interesting to note that under the same storage condition, the effect of feed moisture has not significant differences, but the effect of temperature and storage were significant in all experimental conditions. According to some authors, higher values of WAI are related to higher starch content, which once undergoes degradation enhances water absorption (Gujska *et al.*, 1996). Thus the effect of the storage condition results is the increase in water absorption index.

Table 4.35: Effect of packaging material and storage duration on Water Absorption Index of extrudates.

Sr. No.	Packaging material	0	10	20	30	40	50	60
1	Aluminium foil pouch	4.27 ^a	4.29 ^a	4.32 ^a	4.36 ^b	4.43 ^a	4.48 ^a	4.54 ^a
2	Polyethylene pouch	4.27 ^a	4.33 ^a	4.37 ^a	4.44 ^{ba}	4.51 ^a	4.53 ^a	4.59 ^a
3	Polyester pouch	4.27 ^a	4.31 ^a	4.34 ^a	4.39 ^a	4.46 ^a	4.52 ^a	4.57 ^a
SE		0.0000	0.0233	0.0376	0.0154	0.0201	0.0326	0.0221
CD at 1%		0.0000	0.1043	0.1686	0.069	0.0899	0.1461	0.0991

(Same letter are not significantly different ($p \leq 0.01$))

4.5.2.4 Water solubility index (WSI)

The effect of packaging material and storage period on the water solubility index of extruded prepared with arrowroot (10%), lesser yam (40%) and potato (50%) is presented in Table 4.36.

Table 4.36 shows the effect of packaging material and storage duration on water solubility index of extrudates. The water solubility index increased from 31.34 to 42.67 %, 31.34 to 43.67 % and 31.34 to 43.00 % in aluminium foil pouch, polyethylene pouch and polyester pouch respectively. Table 4.33 (d) shows the ANOVA for change in water solubility index in 60 days storage duration for arrowroot, lesser yam and potato based extrudates.

Increase in water solubility index with increase in storage period from 0-60 days is higher in polyethylene pouch than polyester pouch and aluminium foil pouch for extruded. This increase in water solubility index with increase in storage duration was non significant at $p \leq 0.01$ for extrudates. The effect of packaging materials and storage durations on the water solubility index of the extrudates were non significant at $p \leq 0.01$. As the difference between

the means of water solubility index of extrudates at all the interval for polyethylene pouch, polyester pouch and aluminium foil pouch was lower than CD and has non significant difference at $p \leq 0.01$.

Water solubility index increased with increase in storage durations. Similar findings were reported by Rocha-Guzma'n *et al.*, 2006 for common bean extrusion. A increase in water solubility index was also observed in all the packaging material with the increase in storage period from 0-60 days (non significant difference at $p \leq 0.01$).

Table 4.36: Effect of packaging material and storage duration on Water Solubility Index of extrudates.

Sr. No.	Packaging material	0	10	20	30	40	50	60
1	Aluminium foil pouch	31.34 ^a	32.00 ^a	33.00 ^a	35.67 ^a	37.67 ^a	39.67 ^a	42.67 ^a
2	Polyethylene pouch	31.34 ^a	33.34 ^a	35.00 ^a	37.00 ^a	39.34 ^a	42.34 ^a	43.67 ^a
3	Polyester pouch	31.34 ^a	32.67 ^a	34.00 ^a	36.67 ^a	38.34 ^a	41.67 ^a	43.00 ^a
SE		0.0000	0.5586	1.0220	1.0183	0.4389	0.6266	0.9149
CD at 1%		0.0000	2.5035	4.5805	4.5643	1.967	2.8083	4.1006

(Same letter are not significantly different ($p \leq 0.01$))

4.5.2.5 Hardness (HR)

The effect of packaging material and storage period on the hardness of extruded prepared with proportions of arrowroot (10%), lesser yam (40%) and potato (50%) is presented in Table 4.37.

Table 4.37 shows the effect of packaging material and storage duration on hardness of extrudates. The hardness increased from 1412 to 1658 g, 1412 to 1723 g and 1412 to 1694 g in aluminium foil pouch, polyethylene pouch and polyester pouch respectively. Table 4.33 (e) shows the ANOVA for change in hardness in 60 days storage duration for arrowroot, lesser yam and potato based extrudates.

Increase in hardness with increase in storage period from 0-60 days is higher in polyethylene pouch than polyester pouch and aluminium foil pouch for extrudates. This increase in hardness with increase in storage duration for extrudates was non significant at $p \leq 0.01$. The effect of packaging materials and storage durations on the hardness of the extrudates were non significant at $p \leq 0.01$. As the difference between the means of hardness of extrudates at the entire interval for polyethylene pouch, polyester pouch and aluminium foil pouch was lower than CD and has non significant difference at $p \leq 0.01$ from each other.

Hardness increased with increase in storage durations. A increase in hardness was also observed in all the packaging material with the increase in storage period from 0-60 days (non significant at $p \leq 0.01$). The moisture content increased during the storage period therefore hardness of extrudates also increased. The photomicrograph revealed the presence of relatively much compact and dense structural orientation with numerous globules after 60 days of storage which may have lead to the increase in the hardness of the extrudates and may be the cause for the loss of crispiness of the extrudates.

Table 4.37: Effect of packaging material and storage duration on Hardness of extrudates.

Sr. No.	Packaging material	0	10	20	30	40	50	60
1	Aluminium foil pouch	1412 ^a	1437 ^a	1466 ^a	1532 ^a	1548 ^a	1634 ^a	1658 ^a
2	Polyethylene pouch	1412 ^a	1463 ^a	1542 ^a	1565 ^a	1649 ^a	1688 ^a	1723 ^a
3	Polyester pouch	1412 ^a	1445 ^a	1490 ^a	1542 ^a	1567 ^a	1651 ^a	1694 ^a
SE		0.00	101.20	68.07	36.75	57.25	39.64	90.88
CD at 1%		0.00	453.57	305.09	164.73	256.61	177.69	407.33

(Same letter are not significantly different ($p \leq 0.01$))

APPENDIX A

Drying of Arrowroot, Lesser yam and Potato tuber crops

Appendix A.I: Drying of Arrowroot tuber crops slices at convective hot air drying

Appendix A.I.1: Average value of weight of sample w. r. t time, moisture content, drying rate and moisture ratio of arrowroot tuber crops slices at 60 °C.

Time	Weight loss w.r.t. time (g)				Moisture removed				Moisture content (% db)				Drying rate				MR	In MR
	R1	R2	R3	Avg.	R1	R2	R3	Avg.	R1	R2	R3	Avg.	R1	R2	R3	Avg.		
0	100.00	100.00	100.00	100.00	0.00	0.00	0.00	0.00	124.42	124.42	124.42	124.42	0.00	0.00	0.00	0.00	1.00	0.00
15	97.02	97.12	97.20	97.11	2.98	2.88	2.80	2.89	117.73	117.95	118.13	117.94	0.45	0.43	0.42	0.43	0.95	-0.05
30	94.11	94.22	94.12	94.15	2.91	2.90	3.08	2.96	111.20	111.45	111.22	111.29	0.44	0.43	0.46	0.44	0.89	-0.11
45	91.45	91.22	91.45	91.37	2.66	3.00	2.67	2.78	105.23	104.71	105.23	105.06	0.40	0.45	0.40	0.42	0.84	-0.17
60	89.32	89.14	89.11	89.19	2.13	2.08	2.34	2.18	100.45	100.04	99.98	100.16	0.32	0.31	0.35	0.33	0.81	-0.22
75	87.20	87.14	87.22	87.19	2.12	2.00	1.89	2.00	95.69	95.56	95.74	95.66	0.32	0.30	0.28	0.30	0.77	-0.26
90	85.32	85.21	85.34	85.29	1.88	1.93	1.88	1.90	91.47	91.23	91.52	91.40	0.28	0.29	0.28	0.28	0.73	-0.31
105	84.21	84.23	84.14	84.19	1.11	0.98	1.20	1.10	88.98	89.03	88.82	88.94	0.17	0.15	0.18	0.16	0.71	-0.34
120	83.10	83.21	83.21	83.17	1.11	1.02	0.93	1.02	86.49	86.74	86.74	86.65	0.17	0.15	0.14	0.15	0.70	-0.36

135	81.27	81.76	81.56	81.53	1.83	1.45	1.65	1.64	82.38	83.48	83.03	82.97	0.27	0.22	0.25	0.25	0.67	-0.41
150	78.12	77.76	78.56	78.15	3.15	4.00	3.00	3.38	75.31	74.51	76.30	75.37	0.47	0.60	0.45	0.51	0.61	-0.50
165	74.26	74.26	75.14	74.55	3.86	3.50	3.42	3.59	66.65	66.65	68.63	67.31	0.58	0.52	0.51	0.54	0.54	-0.61
180	72.56	71.78	72.06	72.13	1.70	2.48	3.08	2.42	62.84	61.09	61.71	61.88	0.25	0.37	0.46	0.36	0.50	-0.70
195	69.50	68.46	68.31	68.76	3.06	3.32	3.75	3.38	55.97	53.64	53.30	54.30	0.46	0.50	0.56	0.51	0.44	-0.83
210	66.30	66.28	66.21	66.26	3.20	2.18	2.10	2.49	48.79	48.74	48.59	48.71	0.48	0.33	0.31	0.37	0.39	-0.94
225	64.21	64.24	64.25	64.23	2.09	2.04	1.96	2.03	44.10	44.17	44.19	44.15	0.31	0.31	0.29	0.30	0.35	-1.04
240	62.41	62.43	62.42	62.42	1.80	1.81	1.83	1.81	40.06	40.10	40.08	40.08	0.27	0.27	0.27	0.27	0.32	-1.13
255	60.61	60.66	60.67	60.65	1.80	1.77	1.75	1.77	36.02	36.13	36.15	36.10	0.27	0.26	0.26	0.27	0.29	-1.24
270	58.91	58.98	58.95	58.95	1.70	1.68	1.72	1.70	32.20	32.36	32.29	32.29	0.25	0.25	0.26	0.25	0.26	-1.35
285	57.48	57.48	57.42	57.46	1.43	1.50	1.53	1.49	28.99	28.99	28.86	28.95	0.21	0.22	0.23	0.22	0.23	-1.46
300	56.08	56.19	56.17	56.15	1.40	1.29	1.25	1.31	25.85	26.10	26.05	26.00	0.21	0.19	0.19	0.20	0.21	-1.57
315	54.18	54.12	54.08	54.13	1.90	2.07	2.09	2.02	21.59	21.45	21.36	21.47	0.28	0.31	0.31	0.30	0.17	-1.76
330	53.25	53.11	53.10	53.15	0.93	1.01	0.98	0.97	19.50	19.19	19.17	19.28	0.14	0.15	0.15	0.15	0.16	-1.86
345	52.22	52.29	52.21	52.24	1.03	0.82	0.89	0.91	17.19	17.35	17.17	17.24	0.15	0.12	0.13	0.14	0.14	-1.98
360	51.59	51.57	51.60	51.59	0.63	0.72	0.61	0.65	15.78	15.73	15.80	15.77	0.09	0.11	0.09	0.10	0.13	-2.07
375	50.02	50.18	50.12	50.11	1.57	1.39	1.48	1.48	12.25	12.61	12.48	12.45	0.23	0.21	0.22	0.22	0.10	-2.30
390	49.33	49.34	49.33	49.33	0.69	0.84	0.79	0.77	10.70	10.73	10.70	10.71	0.10	0.13	0.12	0.12	0.09	-2.45

405	48.75	48.73	48.75	48.74	0.58	0.61	0.58	0.59	9.40	9.36	9.40	9.39	0.09	0.09	0.09	0.09	0.08	-2.58
420	48.21	48.19	48.20	48.20	0.54	0.54	0.55	0.54	8.19	8.15	8.17	8.17	0.08	0.08	0.08	0.08	0.07	-2.72
435	48.18	48.00	48.07	48.08	0.03	0.19	0.13	0.12	8.12	7.72	7.88	7.91	0.00	0.03	0.02	0.02	0.06	-2.76
450	48.15	47.95	47.97	48.02	0.03	0.05	0.10	0.06	8.06	7.61	7.65	7.77	0.00	0.01	0.01	0.01	0.06	-2.77
465	48.13	47.92	47.95	48.00	0.02	0.03	0.02	0.02	8.01	7.54	7.61	7.72	0.00	0.00	0.00	0.00	0.06	-2.78
480	48.10	47.87	47.94	47.97	0.03	0.05	0.01	0.03	7.94	7.43	7.59	7.65	0.00	0.01	0.00	0.00	0.06	-2.79
495	48.07	47.85	47.93	47.95	0.03	0.02	0.01	0.02	7.88	7.38	7.56	7.61	0.00	0.00	0.00	0.00	0.06	-2.79

Appendix A.II: Drying of lesser yam tuber crops slices at convective hot air drying

Time	R1	R2	R3	Avg. Wt Loss	M Removed	MC (db) %	MC (wb)%	Water removed (%)	DR (g/min)	MR	ln MR
0	53.582	64.21	88.06	68.617	0.00	361.71	78.34			1.000	0.00
10	50.907	61.69	82.02	64.871	3.75	336.50	77.09	25.20	2.520	0.928	-0.07
20	47.950	58.25	76.41	60.867	4.00	309.56	75.58	26.94	2.694	0.852	-0.16
30	44.158	54.52	71.44	56.705	4.16	281.56	73.79	28.00	2.800	0.772	-0.26
40	40.534	50.76	67.21	52.835	3.87	255.51	71.87	26.05	2.605	0.698	-0.36
50	37.608	47.92	63.55	49.694	3.14	234.38	70.09	21.13	2.113	0.638	-0.45
60	34.061	43.95	60.31	46.108	3.59	210.25	67.77	24.13	2.413	0.570	-0.56
70	31.984	41.58	57.28	43.615	2.49	193.48	65.93	16.77	1.677	0.522	-0.65

80	30.044	38.88	54.53	41.151	2.46	176.90	63.89	16.58	1.658	0.475	-0.74
90	28.187	35.93	51.92	38.679	2.47	160.26	61.58	16.63	1.663	0.428	-0.85
100	26.443	33.43	49.37	36.415	2.26	145.03	59.19	15.24	1.524	0.385	-0.96
110	24.476	30.80	46.94	34.071	2.34	129.25	56.38	15.77	1.577	0.340	-1.08
120	22.889	28.66	44.61	32.052	2.02	115.67	53.63	13.58	1.358	0.301	-1.20
130	21.357	26.70	42.48	30.179	1.87	103.07	50.76	12.60	1.260	0.266	-1.33
140	19.904	25.11	40.47	28.495	1.68	91.74	47.85	11.33	1.133	0.233	-1.46
150	18.161	23.00	38.57	26.575	1.92	78.82	44.08	12.92	1.292	0.197	-1.63
160	17.209	21.88	36.75	25.280	1.30	70.10	41.21	8.72	0.872	0.172	-1.76
170	15.490	20.49	34.98	23.653	1.63	59.16	37.17	10.94	1.094	0.141	-1.96
180	15.250	19.61	33.36	22.737	0.92	52.99	34.64	6.17	0.617	0.123	-2.09
195	14.657	18.92	31.85	21.807	0.93	46.73	31.85	6.26	0.417	0.106	-2.25
210	13.941	18.55	30.39	20.960	0.85	41.03	29.09	5.70	0.380	0.089	-2.41
225	13.621	18.21	29.01	20.281	0.68	36.47	26.72	4.57	0.304	0.076	-2.57
240	13.362	17.60	27.78	19.581	0.70	31.75	24.10	4.71	0.314	0.063	-2.76
255	13.302	17.11	26.59	19.000	0.58	27.85	21.78	3.91	0.261	0.052	-2.96
270	13.150	16.70	25.48	18.443	0.56	24.10	19.42	3.75	0.250	0.041	-3.19
285	13.010	16.33	24.39	17.909	0.53	20.50	17.01	3.59	0.240	0.031	-3.47

300	12.890	16.03	23.34	17.422	0.49	17.23	14.70	3.27	0.218	0.022	-3.83
315	12.810	15.78	22.35	16.979	0.44	14.25	12.47	2.98	0.199	0.013	-4.32
330	12.759	15.57	21.40	16.576	0.40	11.53	10.34	2.71	0.181	0.006	-5.18
345	12.700	15.43	21.16	16.431	0.14	10.56	9.55	0.97	0.065	0.003	-5.85
360	12.698	15.43	20.76	16.294	0.14	9.64	8.79	0.92	0.061	0.000	-8.26
375	12.696	15.42	20.73	16.282	0.01	9.56	8.72	0.08	0.006	0.000	

Appendix A.III: Drying of potato tuber crops slices at convective hot air drying

Appendix A.I.3: Average value of weight of sample w. r. t time, moisture content, drying rate and moisture ratio of potato tuber crops slices at 60 °C.

Time (min)	Weight loss w.r.t time (g)				Moisture removed				Moisture content (% db)				Drying rate				MR	In MR
	R1	R2	R3	Avg.	R1	R2	R3	Avg	R1	R2	R3	Avg	R1	R2	R3	Avg.		
0	50.70	50.67	50.28	50.55	0.00	0.00	0.00	0.00	244.88	244.68	241.98	243.85	0.00	0.00	0.00	0.00	1.00	0.00
15	46.63	46.99	46.56	45.24	4.07	3.69	3.72	3.82	217.20	217.20	216.71	217.04	1.85	1.83	1.68	1.79	0.89	-0.12
30	43.20	45.00	43.05	42.52	3.44	1.99	3.51	2.98	193.82	206.09	192.84	197.58	1.56	0.74	1.59	1.30	0.81	-0.22
45	40.88	42.91	40.06	39.79	2.32	2.09	3.00	2.47	178.06	191.90	172.47	180.81	1.05	0.95	1.36	1.12	0.74	-0.30
60	37.45	40.77	36.68	37.66	3.43	2.14	3.38	2.99	154.73	177.32	149.47	160.50	1.56	0.97	1.53	1.35	0.66	-0.42
75	36.25	39.77	35.07	36.43	1.20	1.00	1.60	1.27	146.58	170.51	138.58	151.89	0.54	0.45	0.73	0.57	0.62	-0.47

90	35.11	38.42	33.97	35.12	1.14	1.35	1.11	1.20	138.84	161.33	131.05	143.74	0.52	0.61	0.50	0.54	0.59	-0.53
105	34.04	37.02	32.17	33.72	1.07	1.40	1.79	1.42	131.56	151.84	118.85	134.09	0.48	0.63	0.81	0.64	0.55	-0.60
120	33.00	35.70	30.38	32.46	1.04	1.33	1.80	1.39	124.49	142.82	106.62	124.64	0.47	0.60	0.82	0.63	0.51	-0.67
135	32.01	34.41	29.28	31.46	0.99	1.29	1.10	1.13	117.75	134.03	99.16	116.98	0.45	0.59	0.50	0.51	0.48	-0.73
150	31.24	33.42	28.37	30.59	0.77	0.98	0.91	0.89	112.52	127.34	93.00	110.95	0.35	0.45	0.41	0.40	0.46	-0.79
165	30.33	32.60	27.56	29.77	0.91	0.82	0.82	0.85	106.30	121.74	87.43	105.16	0.41	0.37	0.37	0.39	0.43	-0.84
180	29.55	31.82	26.75	28.96	0.78	0.78	0.81	0.79	101.00	116.44	81.95	99.79	0.35	0.35	0.37	0.36	0.41	-0.89
195	28.65	31.10	25.92	28.18	0.90	0.72	0.83	0.82	94.87	111.55	76.32	94.24	0.41	0.33	0.38	0.37	0.39	-0.95
210	27.85	30.42	25.18	27.44	0.80	0.68	0.75	0.74	89.41	106.91	71.24	89.19	0.36	0.31	0.34	0.34	0.37	-1.01
225	26.92	29.72	24.57	26.70	0.92	0.70	0.61	0.74	83.13	102.14	67.11	84.13	0.42	0.32	0.28	0.34	0.34	-1.06
240	26.18	28.92	23.87	25.96	0.74	0.79	0.70	0.74	78.09	96.73	62.37	79.07	0.34	0.36	0.32	0.34	0.32	-1.13
255	25.28	28.23	23.28	25.18	0.90	0.70	0.59	0.73	71.98	92.00	58.33	74.10	0.41	0.32	0.27	0.33	0.30	-1.19
270	24.31	27.55	22.42	24.38	0.97	0.67	0.86	0.84	65.37	87.41	52.48	68.42	0.44	0.31	0.39	0.38	0.28	-1.27
285	23.55	26.74	21.70	23.66	0.76	0.81	0.72	0.76	60.21	81.88	47.60	63.23	0.34	0.37	0.33	0.35	0.26	-1.35
300	22.88	26.16	20.95	22.99	0.67	0.58	0.75	0.67	55.65	77.93	42.49	58.69	0.30	0.26	0.34	0.30	0.24	-1.42
315	22.28	25.46	20.19	22.31	0.60	0.70	0.76	0.69	51.57	73.18	37.33	54.02	0.27	0.32	0.34	0.31	0.22	-1.51
330	21.72	24.75	19.47	21.68	0.56	0.71	0.72	0.66	47.76	68.34	32.42	49.51	0.25	0.32	0.33	0.30	0.20	-1.59
345	21.21	23.99	18.96	21.09	0.51	0.76	0.51	0.59	44.28	63.17	28.95	45.47	0.23	0.34	0.23	0.27	0.19	-1.68

360	20.70	23.30	18.41	20.52	0.51	0.69	0.55	0.58	40.80	58.46	25.23	41.50	0.23	0.31	0.25	0.26	0.17	-1.77
375	20.00	22.66	18.06	19.98	0.70	0.63	0.35	0.56	36.04	54.16	22.85	37.68	0.32	0.29	0.16	0.25	0.15	-1.87
390	19.39	21.94	17.86	19.47	0.61	0.73	0.20	0.51	31.87	49.22	21.47	34.19	0.28	0.33	0.09	0.23	0.14	-1.96
405	18.85	21.33	17.46	18.99	0.53	0.61	0.40	0.51	28.23	45.08	18.77	30.70	0.24	0.28	0.18	0.23	0.13	-2.07
420	18.40	20.77	17.16	18.58	0.45	0.56	0.30	0.44	25.15	41.28	16.70	27.71	0.21	0.25	0.14	0.20	0.11	-2.17
435	17.95	20.24	16.94	18.21	0.45	0.53	0.22	0.40	22.10	37.65	15.21	24.99	0.20	0.24	0.10	0.18	0.10	-2.28
450	17.55	19.72	16.87	17.89	0.41	0.52	0.07	0.33	19.35	34.12	14.74	22.74	0.18	0.24	0.03	0.15	0.09	-2.37
465	17.15	19.24	16.83	17.60	0.40	0.48	0.04	0.31	16.65	30.85	14.48	20.66	0.18	0.22	0.02	0.14	0.08	-2.47
480	16.77	18.79	16.81	17.32	0.38	0.45	0.02	0.28	14.08	27.81	14.35	18.74	0.17	0.20	0.01	0.13	0.08	-2.57
495	16.45	18.31	16.77	17.05	0.32	0.48	0.04	0.28	11.87	24.51	14.08	16.82	0.15	0.22	0.02	0.13	0.07	-2.67
510	16.13	17.93	16.75	16.84	0.32	0.38	0.02	0.24	9.71	21.94	13.93	15.19	0.14	0.17	0.01	0.11	0.06	-2.78
525	15.86	17.66	16.73	16.44	0.27	0.27	0.01	0.18	7.90	20.09	13.83	13.94	0.12	0.12	0.01	0.08	0.06	-2.86
540	15.67	16.77	15.93	15.93	0.19	0.88	0.81	0.63	6.62	14.08	8.35	9.68	0.09	0.40	0.37	0.28	0.04	-3.23
555	15.57	15.91	15.73	15.68	0.10	0.87	0.20	0.39	5.92	8.19	6.98	7.03	0.05	0.39	0.09	0.18	0.03	-3.55
570	15.47	15.80	15.63	15.62	0.10	0.11	0.10	0.10	5.23	7.47	6.30	6.33	0.05	0.05	0.05	0.05	0.03	-3.65
585	15.47	15.80	15.53	15.60	0.00	0.00	0.10	0.03	5.22	7.47	5.62	6.10	0.00	0.00	0.05	0.02	0.03	-3.69

APPENDIX B

Appendix B.I: Nutritional properties of flour combinations of raw materials

Sr. No.	Properties	Replications	Treatments								
			T1	T2	T3	T4	T5	T6	T7	T8	T9
1	Protein (%)	R1	5.08	2.28	1.75	3.50	3.50	3.85	4.03	3.50	4.03
		R2	5.43	2.63	2.63	3.33	3.85	4.03	3.85	3.33	4.55
		R3	5.60	2.98	2.45	3.33	2.28	3.68	4.20	3.50	4.20
2	Fat (%)	R1	5.08	2.28	1.75	0.75	0.80	0.80	0.50	0.70	0.50
		R2	5.43	2.63	2.63	1.15	0.55	0.55	0.45	0.45	0.50
		R3	5.60	2.98	2.45	1.05	0.65	0.75	0.50	0.45	0.60
3	Fiber (%)	R1	0.82	1.09	0.43	1.33	1.43	1.50	1.50	1.28	1.25
		R2	0.97	1.08	0.47	1.48	1.36	1.27	1.27	1.47	1.30
		R3	0.82	1.08	0.53	1.37	1.39	1.51	1.51	1.33	1.27
4	Ash (%)	R1	4.06	2.66	4.10	1.90	1.78	2.60	2.69	2.58	2.52
		R2	4.10	2.99	3.49	2.69	1.40	2.19	2.48	2.38	3.20
		R3	4.27	2.69	4.20	2.59	2.57	2.59	2.39	2.56	3.10
5	Moisture (%)	R1	6.96	5.13	8.18	6.89	6.11	7.84	7.53	6.20	6.39
		R2	3.45	9.91	8.67	6.90	6.18	7.86	7.54	6.15	6.39
		R3	7.03	10.64	7.38	6.87	6.14	7.82	7.55	6.10	6.39
6	Carbohydrates (%)	R1	78.01	86.56	83.79	85.63	86.38	83.41	83.75	85.74	85.31
		R2	80.63	80.76	82.12	84.46	86.66	84.11	84.41	86.22	84.07
		R3	76.68	79.64	82.99	84.79	86.97	83.66	83.85	86.06	84.44

Appendix B.II: Functional properties of flour combinations of raw materials

Sr. No.	Properties	Replications	Treatments								
			T1	T2	T3	T4	T5	T6	T7	T8	T9
1	Water absorption capacity (ml/g)	R1	1.30	2.00	2.20	1.90	2.20	1.90	2.00	2.30	1.70
		R2	1.40	2.10	2.70	2.30	2.30	2.40	1.80	1.90	1.90
		R3	1.40	1.90	2.50	2.10	2.10	2.20	1.90	2.00	2.00
2	Oil absorption capacity (ml/g)	R1	1.00	0.90	0.90	1.60	1.20	1.60	1.60	1.30	1.00
		R2	1.50	0.80	0.40	1.60	1.40	1.50	1.20	1.30	1.30
		R3	1.30	1.00	0.60	1.50	1.30	1.60	1.40	1.40	1.10
3	Bulk density (g/cm ³)	R1	2.42	4.47	3.94	3.55	3.56	3.64	4.00	4.00	3.33
		R2	2.42	4.47	4.37	3.90	4.44	4.00	4.00	3.64	4.45
		R3	2.41	4.02	3.93	4.33	3.64	3.33	3.64	4.00	4.00
4	Flour dispersibility (%)	R1	34.00	26.00	42.00	40.00	38.00	40.00	48.00	40.00	38.00
		R2	34.00	22.00	42.00	38.00	38.00	38.00	48.00	42.00	42.00
		R3	34.00	25.00	41.00	40.00	38.00	40.00	52.00	41.00	40.00
5	Yellowness Index	R1	21.27	29.58	33.74	30.05	27.24	26.44	25.51	25.35	24.07
		R2	21.80	27.12	33.52	29.00	27.83	25.51	26.06	25.37	23.93
		R3	21.67	28.25	29.68	28.10	26.81	27.08	26.16	24.86	23.93

APPENDIX C

Appendix C: Nutritional and functional properties of extrudates

Appendix C.I: Nutritional properties of extrudates

Sr. No	Nutritional properties	Temp	RPM	Replication	Treatment					
					T1	T2	T3	T4	T5	T6
1	Protein (%)	130°C	330	R ₁	4.73	4.38	4.55	4.03	2.45	2.10
				R ₂	4.90	4.55	4.38	4.20	2.63	2.10
				R ₃	4.38	4.73	4.38	3.85	2.80	2.28
				Avg	4.67	4.55	4.43	4.03	2.63	2.16
			360	R ₁	3.50	2.98	2.98	2.28	2.10	1.93
				R ₂	3.33	2.98	2.63	2.28	2.28	1.93
				R ₃	3.50	3.15	2.80	2.45	2.10	2.10
				Avg	3.44	3.03	2.80	2.33	2.16	1.98
			390	R ₁	3.15	2.98	2.80	2.63	2.10	1.93
				R ₂	2.98	2.80	2.45	2.10	2.28	1.93
				R ₃	3.15	2.98	2.28	2.10	1.75	1.58
				Avg	3.09	2.92	2.51	2.28	2.04	1.81
		150°C	330	R ₁	4.03	3.68	3.50	2.63	2.63	2.45
				R ₂	4.03	3.85	3.68	2.80	2.45	2.10
				R ₃	4.20	4.03	3.33	2.63	2.28	1.75
				Avg	4.08	3.85	3.50	2.68	2.45	2.10
			360	R ₁	3.15	2.98	2.80	2.45	1.93	1.93
				R ₂	3.33	2.80	2.80	1.93	1.75	1.75
				R ₃	3.50	2.98	2.98	2.10	2.10	1.58
				Avg	3.33	2.92	2.86	2.16	1.93	1.75
			390	R ₁	3.15	2.98	2.63	2.28	2.10	1.75

				R ₂	2.98	2.45	2.45	1.93	1.93	1.93
				R ₃	2.80	2.63	2.10	1.93	1.58	1.40
				Avg	2.98	2.68	2.39	2.04	1.87	1.69
		170°C	330	R ₁	2.98	2.80	2.45	2.45	1.93	1.75
				R ₂	3.15	2.80	2.63	2.28	2.10	1.58
				R ₃	3.33	2.63	2.63	2.45	1.93	1.93
				Avg	3.15	2.74	2.57	2.39	1.98	1.75
			360	R ₁	2.80	2.63	2.45	2.45	2.10	1.58
				R ₂	2.98	2.45	2.45	2.28	1.75	1.93
				R ₃	2.80	2.63	2.63	2.10	1.93	1.58
				Avg	2.86	2.57	2.51	2.28	1.93	1.69
			390	R ₁	2.63	2.63	2.45	2.28	1.93	1.58
				R ₂	2.63	2.28	2.28	2.10	2.10	1.58
				R ₃	2.80	2.45	2.28	2.10	1.58	1.40
				Avg	2.68	2.45	2.33	2.16	1.87	1.52
2	Ash Content (%)	130°C	330	R ₁	1.85	1.7	1.65	1.55	1.47	1.35
				R ₂	1.8	1.75	1.7	1.65	1.5	1.5
				R ₃	1.95	1.65	1.6	1.45	1.4	1.4
				Avg	1.87	1.70	1.65	1.55	1.46	1.42
			360	R ₁	1.95	1.85	1.75	1.75	1.5	1.45
				R ₂	1.95	1.85	1.65	1.7	1.55	1.45
				R ₃	2	1.95	1.85	1.65	1.5	1.45
				Avg	1.97	1.88	1.75	1.70	1.52	1.45
			390	R ₁	2.2	2	1.95	1.9	1.5	1.45
				R ₂	2.15	1.95	1.85	1.85	1.55	1.4
				R ₃	2.1	2	1.8	1.75	1.15	1.5
				Avg	2.15	1.98	1.87	1.83	1.40	1.45
		150°C	330	R ₁	1.9	1.75	1.75	1.65	1.47	1.35
				R ₂	1.85	1.7	1.7	1.6	1.6	1.5
				R ₃	1.9	1.75	1.6	1.65	1.6	1.5
				Avg	1.88	1.73	1.68	1.63	1.56	1.45

			360	R ₁	2.05	1.95	1.9	1.8	1.65	1.55
				R ₂	2.1	2	1.85	1.8	1.6	1.5
				R ₃	2	2	1.9	1.8	1.65	1.7
				Avg	2.05	1.98	1.88	1.80	1.63	1.58
			390	R ₁	2.25	2.05	1.95	1.85	1.75	1.65
				R ₂	2.15	2	1.95	1.9	1.8	1.6
				R ₃	2.3	2	1.95	1.7	1.75	1.65
				Avg	2.23	2.02	1.95	1.82	1.77	1.63
		170°C	330	R ₁	1.95	1.85	1.8	1.65	1.47	1.35
				R ₂	1.95	1.95	1.8	1.7	1.65	1.55
				R ₃	1.95	1.85	1.8	1.7	1.7	1.5
				Avg	1.95	1.88	1.80	1.68	1.61	1.47
			360	R ₁	2	2.1	1.9	1.9	1.75	1.6
				R ₂	2.15	2.1	1.9	1.85	1.7	1.6
				R ₃	2.15	2.1	2	1.8	1.75	1.6
				Avg	2.10	2.10	1.93	1.85	1.73	1.60
			390	R ₁	2.3	2.05	2.05	2	1.85	1.75
				R ₂	2.35	2.15	2	1.95	1.85	1.75
				R ₃	2.3	2.15	2.15	1.9	1.9	1.8
				Avg	2.32	2.12	2.07	1.95	1.87	1.77
3	Moisture content (%)	130°C	330	R ₁	7.00	7.95	7.80	7.80	7.75	7.70
				R ₂	8.15	6.95	6.80	6.65	6.75	6.70
				R ₃	7.05	6.90	6.80	6.80	6.20	6.10
				Avg	7.40	7.27	7.13	7.08	6.90	6.83
			360	R ₁	6.90	6.75	6.75	6.65	7.75	6.50
				R ₂	6.90	7.05	6.70	6.60	6.75	6.50
				R ₃	6.90	6.75	6.70	6.65	6.20	6.60
				Avg	6.90	6.85	6.72	6.63	6.90	6.53
			390	R ₁	6.80	6.65	6.60	6.50	6.50	6.45
				R ₂	6.80	6.65	6.60	6.55	6.50	6.45
				R ₃	6.80	6.65	6.60	6.55	6.50	6.45

				Avg	6.80	6.65	6.60	6.53	6.50	6.45
		150°C	330	R ₁	6.95	6.90	6.75	6.50	6.45	6.35
				R ₂	6.90	6.90	6.75	6.60	6.50	6.40
				R ₃	6.90	6.85	6.80	6.55	6.50	6.35
				Avg	6.92	6.88	6.77	6.55	6.48	6.37
			360	R ₁	6.80	6.60	6.58	6.55	6.40	6.30
				R ₂	6.85	6.60	6.55	6.50	6.40	6.30
				R ₃	6.75	6.60	6.55	6.45	6.40	6.30
				Avg	6.80	6.60	6.56	6.50	6.40	6.30
			390	R ₁	6.60	6.55	6.50	6.45	6.40	5.46
				R ₂	6.60	6.55	6.10	6.20	6.00	6.30
				R ₃	6.60	6.50	6.50	6.20	5.90	6.25
				Avg	6.60	6.53	6.37	6.28	6.10	6.00
		170°C	330	R ₁	6.70	6.60	6.55	6.45	6.35	6.30
				R ₂	6.70	6.65	6.55	6.45	6.35	6.30
				R ₃	6.60	6.55	6.55	6.40	6.35	6.30
				Avg	6.67	6.60	6.55	6.43	6.35	6.30
			360	R ₁	6.75	6.55	6.50	6.40	6.35	6.25
				R ₂	6.60	6.55	6.50	6.40	6.35	6.25
				R ₃	6.70	6.55	6.50	6.40	6.30	6.25
				Avg	6.68	6.55	6.50	6.40	6.33	6.25
			390	R ₁	6.55	6.50	6.45	6.35	6.30	6.25
				R ₂	6.55	6.50	6.45	6.35	6.30	6.25
				R ₃	6.55	6.55	6.45	6.35	6.30	5.80
				Avg	6.55	6.52	6.45	6.35	6.30	6.10
4	Fat (%)	130°C	330	R ₁	1.52	1.50	1.48	1.47	1.43	1.39
				R ₂	1.50		1.46	1.43	1.41	1.38
				R ₃	1.51	1.49	1.48	1.45	1.40	1.37
				Avg	1.51	1.49	1.47	1.45	1.41	1.38
			360	R ₁	1.50	1.45	1.45	1.45	1.43	1.36
				R ₂	1.48	1.40	1.42	1.41	1.37	1.36

				R ₃	1.46	1.50	1.43	1.37	1.38	1.37	
				Avg	1.48	1.45	1.43	1.41	1.39	1.36	
				390	R ₁	1.44	1.42	1.40	1.37	1.35	1.32
					R ₂	1.49	1.43	1.41	1.33	1.34	1.31
					R ₃	1.46	1.41	1.40	1.42	1.33	1.31
					Avg	1.46	1.42	1.40	1.37	1.34	1.31
			150°C	330	R ₁	1.48	1.45	1.43	1.30	1.31	1.32
					R ₂	1.43	1.45	1.43	1.39	1.35	1.33
					R ₃	1.52	1.45	1.44	1.48	1.36	1.31
					Avg	1.48	1.45	1.43	1.39	1.34	1.32
				360	R ₁	1.45	1.36	1.34	1.32	1.29	1.27
					R ₂	1.41	1.35	1.30	1.31	1.28	1.25
		R ₃			1.40	1.38	1.35	1.28	1.28	1.27	
		Avg			1.42	1.36	1.33	1.30	1.28	1.26	
		390		R ₁	1.38	1.34	1.32	1.26	1.28	1.23	
				R ₂	1.37	1.33	1.30	1.27	1.25	1.23	
				R ₃	1.36	1.35	1.28	1.28	1.25	1.24	
				Avg	1.37	1.34	1.30	1.27	1.26	1.23	
		170°C		330	R ₁	1.42	1.38	1.35	1.32	1.31	1.29
					R ₂	1.45	1.37	1.39	1.33	1.31	1.33
					R ₃	1.39	1.39	1.31	1.33	1.32	1.25
					Avg	1.42	1.38	1.35	1.33	1.31	1.29
				360	R ₁	1.33	1.33	1.41	1.28	1.25	1.21
					R ₂	1.38	1.32	1.20	1.28	1.23	1.18
			R ₃		1.43	1.31	1.19	1.29	1.27	1.24	
			Avg		1.38	1.32	1.27	1.28	1.25	1.21	
			390	R ₁	1.32	1.30	1.28	1.20	1.21	1.18	
				R ₂	1.35	1.31	1.27	1.22	1.17	1.13	
				R ₃	1.38	1.30	1.29	1.24	1.25	1.23	
				Avg	1.35	1.30	1.28	1.22	1.21	1.18	
5	Fibre content (%)		130°C	330	R ₁	1.23	1.28	1.32	1.30	1.35	1.41

				R ₂	1.25	1.27	1.29	1.33	1.35	1.37
				R ₃	1.22	1.26	1.26	1.36	1.36	1.38
				Avg	1.23	1.27	1.29	1.33	1.35	1.39
			360	R ₁	1.20	1.25	1.30	1.32	1.34	1.39
				R ₂	1.20	1.26	1.28	1.31	1.33	1.36
				R ₃	1.21	1.25	1.26	1.31	1.35	1.35
				Avg	1.20	1.25	1.28	1.31	1.34	1.37
			390	R ₁	1.12	1.20	1.25	1.40	1.40	1.35
				R ₂	1.29	1.22	1.27	1.31	1.31	1.34
				R ₃	1.20	1.27	1.30	1.23	1.23	1.31
				Avg	1.20	1.23	1.27	1.31	1.31	1.33
		150°C	330	R ₁	1.23	1.24	1.26	1.33	1.32	1.35
				R ₂	1.21	1.23	1.28	1.30	1.34	1.35
				R ₃	1.18	1.23	1.24	1.28	1.30	1.36
				Avg	1.21	1.23	1.26	1.30	1.32	1.35
			360	R ₁	1.18	1.25	1.25	1.28	1.30	1.33
				R ₂	1.17	1.17	1.31	1.30	1.33	1.39
				R ₃	1.19	1.21	1.19	1.27	1.27	1.27
				Avg	1.18	1.21	1.25	1.28	1.30	1.33
			390	R ₁	1.10	1.17	1.10	1.25	1.28	1.31
				R ₂	1.14	1.18	1.20	1.25	1.28	1.30
				R ₃	1.18	1.19	1.30	1.24	1.27	1.31
				Avg	1.14	1.18	1.20	1.25	1.28	1.31
		170°C	330	R ₁	1.17	1.20	1.20	1.27	1.35	1.32
				R ₂	1.17	1.20	1.22	1.29	1.30	1.36
				R ₃	1.18	1.23	1.26	1.25	1.26	1.28
				Avg	1.17	1.21	1.23	1.27	1.30	1.32
			360	R ₁	1.06	1.18	1.22	1.30	1.28	1.30
				R ₂	1.18	1.19	1.21	1.23	1.27	1.30
				R ₃	1.12	1.17	1.21	1.21	1.29	1.30
				Avg	1.12	1.18	1.21	1.25	1.28	1.30

			390	R ₁	1.05	1.13	1.17	1.20	1.23	1.29
				R ₂	1.09	1.15	1.20	1.25	1.22	1.28
				R ₃	1.13	1.11	1.15	1.15	1.21	1.27
				Avg	1.09	1.13	1.17	1.20	1.22	1.28
6	Carbohydrates (%)	130°C	330	R ₁	83.68	83.19	83.17	83.82	85.47	85.93
				R ₂	82.40	83.97	84.33	84.66	86.27	86.82
				R ₃	83.89	83.96	84.46	85.03	86.73	87.34
				Avg	83.32	83.71	83.98	84.50	86.16	86.70
			360	R ₁	84.95	85.72	85.78	86.56	85.88	87.37
				R ₂	85.14	85.47	86.33	86.71	86.72	87.41
				R ₃	84.93	85.40	85.96	86.57	87.47	87.13
				Avg	85.01	85.53	86.02	86.61	86.69	87.30
			390	R ₁	85.26	85.84	86.05	86.35	87.15	87.50
				R ₂	85.34	85.88	86.47	86.90	87.02	87.57
				R ₃	85.34	85.76	86.66	86.88	88.04	87.85
				Avg	85.31	85.83	86.39	86.71	87.41	87.64
		150°C	330	R ₁	84.41	84.99	85.31	86.60	86.82	87.18
				R ₂	84.59	84.87	85.17	86.31	86.76	87.32
				R ₃	84.30	84.70	85.59	86.41	86.96	87.73
				Avg	84.43	84.85	85.36	86.44	86.85	87.41
			360	R ₁	85.47	85.97	86.28	86.65	87.58	87.72
				R ₂	85.30	86.23	86.39	87.27	87.69	87.86
				R ₃	85.16	85.88	86.09	87.25	87.45	88.13
				Avg	85.31	86.03	86.25	87.06	87.57	87.91
			390	R ₁	85.52	85.92	86.50	86.92	87.19	88.60
				R ₂	85.77	86.49	87.00	87.45	87.74	87.64
				R ₃	85.76	86.34	86.87	87.65	88.25	88.16
				Avg	85.68	86.25	86.79	87.34	87.73	88.13
		170°C	330	R ₁	85.78	86.17	86.65	86.86	87.60	87.99
				R ₂	85.58	86.03	86.41	86.96	87.29	87.89
				R ₃	85.56	86.35	86.45	86.87	87.45	87.74

			360	Avg	85.64	86.18	86.51	86.90	87.44	87.87
				R ₁	85.95	86.19	86.54	86.70	87.20	88.05
				R ₂	85.72	86.38	86.73	86.90	87.67	87.69
				R ₃	85.74	86.18	86.43	87.16	87.49	88.06
				Avg	85.80	86.25	86.57	86.92	87.45	87.93
			390	R ₁	86.16	86.40	86.60	86.98	87.49	87.95
				R ₂	86.04	86.61	86.81	87.13	87.36	88.02
				R ₃	85.84	86.44	86.69	87.26	87.77	88.50
				Avg	86.01	86.48	86.70	87.12	87.54	88.16

Appendix C.II: Functional properties of extrudates

Sr. No	Nutritional properties	Temp	RPM	Replication	Treatment					
					T1	T2	T3	T4	T5	T6
1	Expansion ratio	130°C	330	R ₁	2.87	2.66	2.40	2.33	2.28	2.08
				R ₂	2.77	2.59	2.36	2.32	2.23	2.13
				R ₃	2.85	2.44	2.38	2.35	2.24	2.16
				Avg	2.83	2.56	2.38	2.33	2.25	2.12
			360	R ₁	2.99	2.93	2.69	2.27	1.93	2.41
				R ₂	3.02	2.89	2.71	2.15	1.98	2.42
				R ₃	3.00	2.96	2.67	2.16	1.99	2.38
				Avg	3.01	2.93	2.69	2.19	1.96	2.41
			390	R ₁	3.16	3.05	2.80	2.91	2.20	2.53
				R ₂	3.04	3.07	2.76	2.88	2.15	2.42
				R ₃	3.12	3.06	2.78	2.86	2.10	2.47
				Avg	3.11	3.06	2.78	2.88	2.15	2.47
		150°C	330	R ₁	3.39	2.94	3.07	2.66	2.37	2.71
				R ₂	3.37	2.98	2.96	2.64	2.36	2.68
				R ₃	3.32	3.07	2.92	2.61	2.33	2.73

				Avg	3.36	3.00	2.98	2.64	2.35	2.71
				R ₁	3.11	3.21	2.76	2.70	2.79	2.64
				R ₂	3.19	3.22	2.79	2.73	2.59	2.59
				R ₃	3.12	3.20	2.74	2.62	2.61	2.56
			360	Avg	3.14	3.21	2.76	2.68	2.66	2.60
				R ₁	3.34	3.31	3.08	2.46	2.30	2.39
				R ₂	3.37	3.14	2.93	2.56	2.39	2.28
				R ₃	3.36	3.13	3.00	2.44	2.35	2.27
			390	Avg	3.36	3.20	3.00	2.49	2.35	2.31
				R ₁	2.71	2.90	3.01	2.86	2.90	3.55
				R ₂	2.32	2.92	2.83	2.93	2.93	2.86
				R ₃	2.37	2.94	2.78	2.89	3.07	2.84
		170°C	330	Avg	2.47	2.92	2.87	2.89	2.97	3.09
				R ₁	3.05	2.96	3.07	3.09	2.91	2.91
				R ₂	3.13	3.39	3.09	2.99	3.04	2.95
				R ₃	3.05	2.85	3.01	2.97	3.01	2.90
			360	Avg	3.08	3.07	3.05	3.02	2.99	2.92
				R ₁	2.92	3.15	3.13	2.90	2.68	2.93
				R ₂	3.01	3.07	3.05	2.91	2.75	2.94
				R ₃	2.86	3.13	3.02	2.88	2.62	2.86
			390	Avg	2.93	3.12	3.07	2.90	2.69	2.91
				R ₁	0.29	0.37	0.31	0.39	0.57	0.57
				R ₂	0.33	0.27	0.41	0.37	0.40	0.54
				R ₃	0.23	0.30	0.34	0.38	0.42	0.56
			330	Avg	0.28	0.32	0.35	0.38	0.46	0.55
				R ₁	0.19	0.15	0.15	0.21	0.46	0.25
				R ₂	0.19	0.16	0.18	0.23	0.33	0.31
				R ₃	0.15	0.16	0.17	0.18	0.20	0.30
			360	Avg	0.18	0.16	0.17	0.21	0.33	0.29
				R ₁	0.17	0.18	0.16	0.14	0.47	0.33
				R ₂	0.18	0.15	0.21	0.13	0.38	0.24

				R ₃	0.15	0.19	0.16	0.25	0.51	0.30
				Avg	0.17	0.17	0.18	0.17	0.45	0.29
		150°C	330	R ₁	0.11	0.29	0.16	0.33	0.33	0.26
				R ₂	0.12	0.22	0.19	0.23	0.31	0.24
				R ₃	0.13	0.25	0.22	0.28	0.32	0.26
				Avg	0.12	0.25	0.19	0.28	0.32	0.25
			360	R ₁	0.22	0.17	0.13	0.23	0.19	0.21
				R ₂	0.15	0.11	0.23	0.15	0.30	0.27
				R ₃	0.17	0.18	0.15	0.28	0.22	0.23
				Avg	0.18	0.15	0.17	0.22	0.24	0.24
			390	R ₁	0.11	0.13	0.10	0.16	0.27	0.28
				R ₂	0.13	0.15	0.15	0.17	0.26	0.42
				R ₃	0.17	0.12	0.12	0.14	0.29	0.25
				Avg	0.14	0.14	0.12	0.16	0.27	0.31
		170°C	330	R ₁	0.24	0.14	0.18	0.10	0.17	0.13
				R ₂	0.18	0.15	0.23	0.17	0.24	0.16
				R ₃	0.17	0.15	0.24	0.11	0.24	0.21
				Avg	0.20	0.15	0.21	0.13	0.22	0.17
			360	R ₁	0.20	0.22	0.17	0.16	0.24	0.16
				R ₂	0.14	0.14	0.14	0.21	0.19	0.16
				R ₃	0.16	0.23	0.12	0.17	0.18	0.13
				Avg	0.17	0.20	0.14	0.18	0.20	0.15
			390	R ₁	0.22	0.15	0.17	0.21	0.21	0.18
				R ₂	0.19	0.19	0.19	0.18	0.27	0.19
				R ₃	0.20	0.17	0.19	0.17	0.23	0.22
				Avg	0.20	0.17	0.18	0.19	0.24	0.20
3	Water Absorption Index (g/g)	130°C	330	R ₁	4.40	4.20	5.60	5.00	4.80	5.00
				R ₂	4.60	4.30	5.50	4.80	4.80	4.80
				R ₃	4.60	4.20	5.40	4.60	4.80	4.80
				Avg	4.53	4.23	5.50	4.80	4.80	4.87
			360	R ₁	3.80	4.20	4.00	3.20	4.20	4.00

		150°C		R ₂	3.60	4.20	4.00	3.20	4.40	3.80
				R ₃	3.80	4.40	4.40	3.20	4.60	3.70
				Avg	3.73	4.27	4.13	3.20	4.40	3.83
			390	R ₁	3.80	4.20	4.20	4.40	5.00	3.80
				R ₂	3.80	4.40	4.20	4.60	4.80	3.20
				R ₃	3.60	4.20	4.20	4.20	4.60	3.60
				Avg	3.73	4.27	4.20	4.40	4.80	3.53
			170°C	330	R ₁	4.60	4.00	3.00	3.40	4.00
					R ₂	4.80	4.00	2.60	3.80	3.80
					R ₃	4.60	3.80	2.60	4.00	3.90
					Avg	4.67	3.93	2.73	3.73	3.90
				360	R ₁	4.80	4.00	4.00	6.60	4.60
					R ₂	5.20	4.20	4.00	5.60	4.80
					R ₃	4.80	4.80	4.40	5.40	4.80
					Avg	4.93	4.33	4.13	5.87	4.73
				390	R ₁	3.60	4.20	3.80	5.60	4.60
					R ₂	3.80	4.00	4.20	5.40	4.20
					R ₃	4.00	4.00	4.00	5.20	4.80
					Avg	3.80	4.07	4.00	5.40	4.47
				330	R ₁	5.20	3.80	2.80	5.20	4.00
					R ₂	5.00	4.00	3.20	5.00	4.40
					R ₃	4.80	4.20	3.00	4.60	4.20
					Avg	5.00	4.00	3.00	4.93	4.20
				360	R ₁	4.20	3.80	4.20	4.40	3.60
					R ₂	4.80	3.60	4.60	5.20	3.20
					R ₃	4.60	3.20	4.00	5.00	3.40
					Avg	4.53	3.53	4.27	4.87	3.40
				390	R ₁	2.80	4.80	4.20	4.60	5.20
					R ₂	3.20	4.20	4.40	4.80	4.80
					R ₃	3.00	4.60	4.60	5.00	5.00
					Avg	3.00	4.53	4.40	4.80	4.87

4	Water Solubility Index (%)	130°C	330	R ₁	38.00	36.00	30.00	26.00	26.00	22.00
				R ₂	36.00	34.00	32.00	28.00	24.00	18.00
				R ₃	40.00	30.00	34.00	28.00	20.00	24.00
				Avg	38.00	33.33	32.00	27.33	23.33	21.33
			360	R ₁	36.00	34.00	30.00	28.00	22.00	20.00
				R ₂	38.00	32.00	32.00	24.00	24.00	18.00
				R ₃	36.00	30.00	26.00	26.00	16.00	22.00
				Avg	36.67	32.00	29.33	26.00	20.67	20.00
			390	R ₁	36.00	34.00	30.00	26.00	24.00	18.00
				R ₂	32.00	32.00	26.00	28.00	22.00	22.00
				R ₃	34.00	28.00	24.00	20.00	18.00	16.00
				Avg	34.00	31.33	26.67	24.67	21.33	18.67
		150°C	330	R ₁	40.00	36.00	30.00	28.00	22.00	18.00
				R ₂	36.00	30.00	32.00	26.00	18.00	20.00
				R ₃	34.00	32.00	28.00	22.00	24.00	14.00
				Avg	36.67	32.67	30.00	25.33	21.33	17.33
			360	R ₁	34.00	32.00	28.00	26.00	24.00	18.00
				R ₂	36.00	26.00	26.00	24.00	18.00	16.00
				R ₃	32.00	34.00	32.00	22.00	16.00	14.00
				Avg	34.00	30.67	28.67	24.00	19.33	16.00
			390	R ₁	34.00	32.00	22.00	24.00	22.00	16.00
				R ₂	32.00	30.00	26.00	22.00	14.00	12.00
				R ₃	28.00	26.00	24.00	18.00	16.00	22.00
				Avg	31.33	29.33	24.00	21.33	17.33	16.67
		170°C	330	R ₁	38.00	34.00	32.00	30.00	24.00	16.00
				R ₂	32.00	30.00	30.00	26.00	22.00	14.00
				R ₃	34.00	28.00	24.00	20.00	16.00	20.00
				Avg	34.67	30.67	28.67	25.33	20.67	16.67
			360	R ₁	30.00	28.00	28.00	26.00	22.00	20.00
				R ₂	32.00	26.00	24.00	22.00	18.00	16.00
				R ₃	36.00	30.00	28.00	20.00	16.00	12.00

				Avg	32.67	28.00	26.67	22.67	18.67	16.00
			390	R ₁	32.00	28.00	26.00	22.00	18.00	16.00
				R ₂	32.00	26.00	22.00	16.00	16.00	14.00
				R ₃	28.00	24.00	20.00	20.00	14.00	16.00
				Avg	30.67	26.00	22.67	19.33	16.00	15.33
5	Hardness (g)	130°C	330	R ₁	3290.00	8305.00	11900.00	15905.00	11520.00	30315.00
				R ₂	2230.00	3670.00	11912.00	18755.00	12470.00	21345.00
				R ₃	2835.00	6180.00	12740.00	19905.00	11845.00	28270.00
				Avg	2785.00	6051.67	12184.00	18188.33	11945.00	26643.33
			360	R ₁	2765.00	2140.00	1825.00	1280.00	8510.00	4820.00
				R ₂	2660.00	2735.00	1605.00	1680.00	7985.00	1705.00
				R ₃	3040.00	1585.00	2170.00	1725.00	9805.00	2845.00
				Avg	2821.67	2153.33	1866.67	1561.67	8766.67	3123.33
			390	R ₁	1380.00	1505.00	3695.00	2875.00	11660.00	14780.00
				R ₂	1010.00	940.00	2490.00	1735.00	15700.00	11135.00
				R ₃	850.00	1790.00	4435.00	2470.00	17395.00	19215.00
				Avg	1080.00	1411.67	3540.00	2360.00	14918.33	15043.33
		150°C	330	R ₁	2380.00	2580.00	1045.00	6590.00	6085.00	4475.00
				R ₂	1210.00	2665.00	2995.00	6565.00	10240.00	5745.00
				R ₃	1380.00	4825.00	2900.00	6360.00	6670.00	3250.00
				Avg	1656.67	3356.67	2313.33	6505.00	7665.00	4490.00
			360	R ₁	1755.00	1495.00	2595.00	1950.00	4650.00	10245.00
				R ₂	1860.00	1430.00	1510.00	2585.00	6845.00	8630.00
				R ₃	1785.00	825.00	3525.00	6615.00	3320.00	6895.00
				Avg	1800.00	1250.00	2543.33	3716.67	4938.33	8590.00
			390	R ₁	3100.00	2875.00	1305.00	1630.00	4230.00	15445.00
				R ₂	2230.00	1305.00	1120.00	2545.00	2465.00	11410.00
				R ₃	2245.00	2145.00	830.00	2630.00	3965.00	16415.00
				Avg	2525.00	2108.33	1085.00	2268.33	3553.33	14423.33
		170°C	330	R ₁	3270.00	2005.00	3205.00	3750.00	3945.00	3395.00
				R ₂	1550.00	1555.00	1765.00	2470.00	4980.00	3455.00

6	Yellowness Index	130°C		R ₃	2955.00	2605.00	3560.00	1420.00	3255.00	2600.00
				Avg	2591.67	2055.00	2843.33	2546.67	4060.00	3150.00
			360	R ₁	1875.00	1650.00	3510.00	2615.00	1795.00	4460.00
				R ₂	1520.00	2440.00	2555.00	3755.00	3685.00	3920.00
				R ₃	3300.00	1185.00	2365.00	2115.00	2655.00	3688.00
				Avg	2231.67	1758.33	2810.00	2828.33	2711.67	4022.67
			390	R ₁	2020.00	3115.00	3825.00	2115.00	4000.00	2550.00
				R ₂	1705.00	2320.00	2810.00	2904.00	2235.00	3270.00
				R ₃	2070.00	2035.00	2380.00	2295.00	5115.00	2440.00
				Avg	1931.67	2490.00	3005.00	2438.00	3783.33	2753.33
			330	R ₁	5.87	5.86	5.82	5.30	5.41	4.63
				R ₂	5.86	5.87	5.83	5.31	5.42	4.64
				R ₃	5.88	5.88	5.84	5.32	5.43	4.62
				Avg	5.87	5.87	5.83	5.31	5.42	4.63
			360	R ₁	5.32	4.71	4.61	5.49	5.54	4.56
				R ₂	5.33	4.72	4.63	5.50	5.53	4.57
				R ₃	5.34	4.70	4.62	5.51	5.52	4.58
				Avg	5.33	4.71	4.62	5.50	5.53	4.57
			390	R ₁	4.94	4.95	4.76	5.06	5.29	5.36
				R ₂	4.96	4.96	4.74	5.04	5.28	5.37
				R ₃	4.95	4.98	4.75	5.05	5.27	5.38
				Avg	4.95	4.96	4.75	5.05	5.28	5.37
		150°C	330	R ₁	5.06	5.48	4.83	4.52	4.62	4.56
				R ₂	5.05	4.50	4.85	4.54	4.64	4.58
				R ₃	5.07	5.49	4.84	4.53	4.63	4.57
				Avg	5.06	5.16	4.84	4.53	4.63	4.57
			360	R ₁	5.74	5.31	5.18	5.51	4.55	4.57
				R ₂	5.76	5.30	5.20	5.49	4.54	4.56
				R ₃	5.75	5.32	5.19	5.50	4.56	4.55
				Avg	5.75	5.31	5.19	5.50	4.55	4.56
			390	R ₁	4.78	4.87	4.52	4.90	4.69	4.50

				R ₂	4.80	4.88	4.54	4.88	4.70	4.52
				R ₃	4.79	4.89	4.53	4.89	4.68	4.51
				Avg	4.79	4.88	4.53	4.89	4.69	4.51
		170°C	330	R ₁	5.46	5.02	5.09	4.74	4.52	4.96
				R ₂	5.49	5.01	5.10	4.75	4.53	4.97
				R ₃	5.47	4.90	5.11	4.76	4.54	4.98
				Avg	5.47	4.98	5.10	4.75	4.53	4.97
			360	R ₁	5.14	4.50	4.95	5.18	4.86	4.77
				R ₂	5.15	4.51	4.96	5.19	4.87	4.78
				R ₃	5.16	4.52	4.97	5.20	4.88	4.79
				Avg	5.15	4.51	4.96	5.19	4.87	4.78
			390	R ₁	5.49	4.63	5.36	5.02	4.90	4.93
				R ₂	5.50	4.64	5.37	5.03	4.91	4.94
				R ₃	5.51	4.65	5.38	5.04	4.92	4.95
				Avg	5.50	4.64	5.37	5.03	4.91	4.94

APPENDIX C

Appendix C: Nutritional and functional properties of extrudates

Appendix C.I: Nutritional properties of extrudates

Sr. No	Nutritional properties	Temp	RPM	Replication	Treatment					
					T1	T2	T3	T4	T5	T6
1	Protein (%)	130°C	330	R ₁	4.73	4.38	4.55	4.03	2.45	2.10
				R ₂	4.90	4.55	4.38	4.20	2.63	2.10
				R ₃	4.38	4.73	4.38	3.85	2.80	2.28
				Avg	4.67	4.55	4.43	4.03	2.63	2.16
			360	R ₁	3.50	2.98	2.98	2.28	2.10	1.93
				R ₂	3.33	2.98	2.63	2.28	2.28	1.93
				R ₃	3.50	3.15	2.80	2.45	2.10	2.10
				Avg	3.44	3.03	2.80	2.33	2.16	1.98
			390	R ₁	3.15	2.98	2.80	2.63	2.10	1.93
				R ₂	2.98	2.80	2.45	2.10	2.28	1.93
				R ₃	3.15	2.98	2.28	2.10	1.75	1.58
				Avg	3.09	2.92	2.51	2.28	2.04	1.81
		150°C	330	R ₁	4.03	3.68	3.50	2.63	2.63	2.45
				R ₂	4.03	3.85	3.68	2.80	2.45	2.10
				R ₃	4.20	4.03	3.33	2.63	2.28	1.75
				Avg	4.08	3.85	3.50	2.68	2.45	2.10
			360	R ₁	3.15	2.98	2.80	2.45	1.93	1.93
				R ₂	3.33	2.80	2.80	1.93	1.75	1.75
				R ₃	3.50	2.98	2.98	2.10	2.10	1.58
				Avg	3.33	2.92	2.86	2.16	1.93	1.75
			390	R ₁	3.15	2.98	2.63	2.28	2.10	1.75

				R ₂	2.98	2.45	2.45	1.93	1.93	1.93
				R ₃	2.80	2.63	2.10	1.93	1.58	1.40
				Avg	2.98	2.68	2.39	2.04	1.87	1.69
		170°C	330	R ₁	2.98	2.80	2.45	2.45	1.93	1.75
				R ₂	3.15	2.80	2.63	2.28	2.10	1.58
				R ₃	3.33	2.63	2.63	2.45	1.93	1.93
				Avg	3.15	2.74	2.57	2.39	1.98	1.75
			360	R ₁	2.80	2.63	2.45	2.45	2.10	1.58
				R ₂	2.98	2.45	2.45	2.28	1.75	1.93
				R ₃	2.80	2.63	2.63	2.10	1.93	1.58
				Avg	2.86	2.57	2.51	2.28	1.93	1.69
			390	R ₁	2.63	2.63	2.45	2.28	1.93	1.58
				R ₂	2.63	2.28	2.28	2.10	2.10	1.58
				R ₃	2.80	2.45	2.28	2.10	1.58	1.40
				Avg	2.68	2.45	2.33	2.16	1.87	1.52
2	Ash Content (%)	130°C	330	R ₁	1.85	1.7	1.65	1.55	1.47	1.35
				R ₂	1.8	1.75	1.7	1.65	1.5	1.5
				R ₃	1.95	1.65	1.6	1.45	1.4	1.4
				Avg	1.87	1.70	1.65	1.55	1.46	1.42
			360	R ₁	1.95	1.85	1.75	1.75	1.5	1.45
				R ₂	1.95	1.85	1.65	1.7	1.55	1.45
				R ₃	2	1.95	1.85	1.65	1.5	1.45
				Avg	1.97	1.88	1.75	1.70	1.52	1.45
			390	R ₁	2.2	2	1.95	1.9	1.5	1.45
				R ₂	2.15	1.95	1.85	1.85	1.55	1.4
				R ₃	2.1	2	1.8	1.75	1.15	1.5
				Avg	2.15	1.98	1.87	1.83	1.40	1.45
		150°C	330	R ₁	1.9	1.75	1.75	1.65	1.47	1.35
				R ₂	1.85	1.7	1.7	1.6	1.6	1.5
				R ₃	1.9	1.75	1.6	1.65	1.6	1.5
				Avg	1.88	1.73	1.68	1.63	1.56	1.45

			360	R ₁	2.05	1.95	1.9	1.8	1.65	1.55
				R ₂	2.1	2	1.85	1.8	1.6	1.5
				R ₃	2	2	1.9	1.8	1.65	1.7
				Avg	2.05	1.98	1.88	1.80	1.63	1.58
			390	R ₁	2.25	2.05	1.95	1.85	1.75	1.65
				R ₂	2.15	2	1.95	1.9	1.8	1.6
				R ₃	2.3	2	1.95	1.7	1.75	1.65
				Avg	2.23	2.02	1.95	1.82	1.77	1.63
		170°C	330	R ₁	1.95	1.85	1.8	1.65	1.47	1.35
				R ₂	1.95	1.95	1.8	1.7	1.65	1.55
				R ₃	1.95	1.85	1.8	1.7	1.7	1.5
				Avg	1.95	1.88	1.80	1.68	1.61	1.47
			360	R ₁	2	2.1	1.9	1.9	1.75	1.6
				R ₂	2.15	2.1	1.9	1.85	1.7	1.6
				R ₃	2.15	2.1	2	1.8	1.75	1.6
				Avg	2.10	2.10	1.93	1.85	1.73	1.60
			390	R ₁	2.3	2.05	2.05	2	1.85	1.75
				R ₂	2.35	2.15	2	1.95	1.85	1.75
				R ₃	2.3	2.15	2.15	1.9	1.9	1.8
				Avg	2.32	2.12	2.07	1.95	1.87	1.77
3	Moisture content (%)	130°C	330	R ₁	7.00	7.95	7.80	7.80	7.75	7.70
				R ₂	8.15	6.95	6.80	6.65	6.75	6.70
				R ₃	7.05	6.90	6.80	6.80	6.20	6.10
				Avg	7.40	7.27	7.13	7.08	6.90	6.83
			360	R ₁	6.90	6.75	6.75	6.65	7.75	6.50
				R ₂	6.90	7.05	6.70	6.60	6.75	6.50
				R ₃	6.90	6.75	6.70	6.65	6.20	6.60
				Avg	6.90	6.85	6.72	6.63	6.90	6.53
			390	R ₁	6.80	6.65	6.60	6.50	6.50	6.45
				R ₂	6.80	6.65	6.60	6.55	6.50	6.45
				R ₃	6.80	6.65	6.60	6.55	6.50	6.45

		150°C	330	Avg	6.80	6.65	6.60	6.53	6.50	6.45
				R ₁	6.95	6.90	6.75	6.50	6.45	6.35
				R ₂	6.90	6.90	6.75	6.60	6.50	6.40
				R ₃	6.90	6.85	6.80	6.55	6.50	6.35
				Avg	6.92	6.88	6.77	6.55	6.48	6.37
			360	R ₁	6.80	6.60	6.58	6.55	6.40	6.30
				R ₂	6.85	6.60	6.55	6.50	6.40	6.30
				R ₃	6.75	6.60	6.55	6.45	6.40	6.30
				Avg	6.80	6.60	6.56	6.50	6.40	6.30
			390	R ₁	6.60	6.55	6.50	6.45	6.40	5.46
				R ₂	6.60	6.55	6.10	6.20	6.00	6.30
				R ₃	6.60	6.50	6.50	6.20	5.90	6.25
				Avg	6.60	6.53	6.37	6.28	6.10	6.00
		170°C	330	R ₁	6.70	6.60	6.55	6.45	6.35	6.30
				R ₂	6.70	6.65	6.55	6.45	6.35	6.30
				R ₃	6.60	6.55	6.55	6.40	6.35	6.30
				Avg	6.67	6.60	6.55	6.43	6.35	6.30
			360	R ₁	6.75	6.55	6.50	6.40	6.35	6.25
				R ₂	6.60	6.55	6.50	6.40	6.35	6.25
				R ₃	6.70	6.55	6.50	6.40	6.30	6.25
				Avg	6.68	6.55	6.50	6.40	6.33	6.25
			390	R ₁	6.55	6.50	6.45	6.35	6.30	6.25
				R ₂	6.55	6.50	6.45	6.35	6.30	6.25
				R ₃	6.55	6.55	6.45	6.35	6.30	5.80
				Avg	6.55	6.52	6.45	6.35	6.30	6.10
4	Fat (%)	130°C	330	R ₁	1.52	1.50	1.48	1.47	1.43	1.39
				R ₂	1.50		1.46	1.43	1.41	1.38
				R ₃	1.51	1.49	1.48	1.45	1.40	1.37
				Avg	1.51	1.49	1.47	1.45	1.41	1.38
			360	R ₁	1.50	1.45	1.45	1.45	1.43	1.36
				R ₂	1.48	1.40	1.42	1.41	1.37	1.36

				390	R ₃	1.46	1.50	1.43	1.37	1.38	1.37	
					Avg	1.48	1.45	1.43	1.41	1.39	1.36	
					R ₁	1.44	1.42	1.40	1.37	1.35	1.32	
					R ₂	1.49	1.43	1.41	1.33	1.34	1.31	
					R ₃	1.46	1.41	1.40	1.42	1.33	1.31	
					Avg	1.46	1.42	1.40	1.37	1.34	1.31	
			150°C	330	R ₁	1.48	1.45	1.43	1.30	1.31	1.32	
					R ₂	1.43	1.45	1.43	1.39	1.35	1.33	
					R ₃	1.52	1.45	1.44	1.48	1.36	1.31	
					Avg	1.48	1.45	1.43	1.39	1.34	1.32	
				360	R ₁	1.45	1.36	1.34	1.32	1.29	1.27	
					R ₂	1.41	1.35	1.30	1.31	1.28	1.25	
					R ₃	1.40	1.38	1.35	1.28	1.28	1.27	
					Avg	1.42	1.36	1.33	1.30	1.28	1.26	
				390	R ₁	1.38	1.34	1.32	1.26	1.28	1.23	
					R ₂	1.37	1.33	1.30	1.27	1.25	1.23	
					R ₃	1.36	1.35	1.28	1.28	1.25	1.24	
					Avg	1.37	1.34	1.30	1.27	1.26	1.23	
				170°C	330	R ₁	1.42	1.38	1.35	1.32	1.31	1.29
						R ₂	1.45	1.37	1.39	1.33	1.31	1.33
						R ₃	1.39	1.39	1.31	1.33	1.32	1.25
						Avg	1.42	1.38	1.35	1.33	1.31	1.29
					360	R ₁	1.33	1.33	1.41	1.28	1.25	1.21
						R ₂	1.38	1.32	1.20	1.28	1.23	1.18
			R ₃			1.43	1.31	1.19	1.29	1.27	1.24	
			Avg			1.38	1.32	1.27	1.28	1.25	1.21	
			390		R ₁	1.32	1.30	1.28	1.20	1.21	1.18	
					R ₂	1.35	1.31	1.27	1.22	1.17	1.13	
					R ₃	1.38	1.30	1.29	1.24	1.25	1.23	
					Avg	1.35	1.30	1.28	1.22	1.21	1.18	
5	Fibre content (%)	130°C	330	R ₁	1.23	1.28	1.32	1.30	1.35	1.41		

					R ₂	1.25	1.27	1.29	1.33	1.35	1.37
					R ₃	1.22	1.26	1.26	1.36	1.36	1.38
					Avg	1.23	1.27	1.29	1.33	1.35	1.39
				360	R ₁	1.20	1.25	1.30	1.32	1.34	1.39
					R ₂	1.20	1.26	1.28	1.31	1.33	1.36
					R ₃	1.21	1.25	1.26	1.31	1.35	1.35
					Avg	1.20	1.25	1.28	1.31	1.34	1.37
				390	R ₁	1.12	1.20	1.25	1.40	1.40	1.35
					R ₂	1.29	1.22	1.27	1.31	1.31	1.34
					R ₃	1.20	1.27	1.30	1.23	1.23	1.31
					Avg	1.20	1.23	1.27	1.31	1.31	1.33
		150°C	330	R ₁	1.23	1.24	1.26	1.33	1.33	1.32	1.35
				R ₂	1.21	1.23	1.28	1.30	1.30	1.34	1.35
				R ₃	1.18	1.23	1.24	1.28	1.28	1.30	1.36
				Avg	1.21	1.23	1.26	1.30	1.32	1.32	1.35
			360	R ₁	1.18	1.25	1.25	1.28	1.30	1.30	1.33
				R ₂	1.17	1.17	1.31	1.30	1.33	1.33	1.39
				R ₃	1.19	1.21	1.19	1.27	1.27	1.27	1.27
				Avg	1.18	1.21	1.25	1.28	1.30	1.30	1.33
			390	R ₁	1.10	1.17	1.10	1.25	1.28	1.28	1.31
				R ₂	1.14	1.18	1.20	1.25	1.28	1.28	1.30
				R ₃	1.18	1.19	1.30	1.24	1.27	1.27	1.31
				Avg	1.14	1.18	1.20	1.25	1.28	1.28	1.31
		170°C	330	R ₁	1.17	1.20	1.20	1.27	1.35	1.35	1.32
				R ₂	1.17	1.20	1.22	1.29	1.30	1.30	1.36
				R ₃	1.18	1.23	1.26	1.25	1.26	1.26	1.28
				Avg	1.17	1.21	1.23	1.27	1.30	1.30	1.32
			360	R ₁	1.06	1.18	1.22	1.30	1.28	1.28	1.30
				R ₂	1.18	1.19	1.21	1.23	1.27	1.27	1.30
				R ₃	1.12	1.17	1.21	1.21	1.29	1.29	1.30
				Avg	1.12	1.18	1.21	1.25	1.28	1.28	1.30

			390	R ₁	1.05	1.13	1.17	1.20	1.23	1.29
				R ₂	1.09	1.15	1.20	1.25	1.22	1.28
				R ₃	1.13	1.11	1.15	1.15	1.21	1.27
				Avg	1.09	1.13	1.17	1.20	1.22	1.28
6	Carbohydrates (%)	130°C	330	R ₁	83.68	83.19	83.17	83.82	85.47	85.93
				R ₂	82.40	83.97	84.33	84.66	86.27	86.82
				R ₃	83.89	83.96	84.46	85.03	86.73	87.34
				Avg	83.32	83.71	83.98	84.50	86.16	86.70
			360	R ₁	84.95	85.72	85.78	86.56	85.88	87.37
				R ₂	85.14	85.47	86.33	86.71	86.72	87.41
				R ₃	84.93	85.40	85.96	86.57	87.47	87.13
				Avg	85.01	85.53	86.02	86.61	86.69	87.30
			390	R ₁	85.26	85.84	86.05	86.35	87.15	87.50
				R ₂	85.34	85.88	86.47	86.90	87.02	87.57
				R ₃	85.34	85.76	86.66	86.88	88.04	87.85
				Avg	85.31	85.83	86.39	86.71	87.41	87.64
		150°C	330	R ₁	84.41	84.99	85.31	86.60	86.82	87.18
				R ₂	84.59	84.87	85.17	86.31	86.76	87.32
				R ₃	84.30	84.70	85.59	86.41	86.96	87.73
				Avg	84.43	84.85	85.36	86.44	86.85	87.41
			360	R ₁	85.47	85.97	86.28	86.65	87.58	87.72
				R ₂	85.30	86.23	86.39	87.27	87.69	87.86
				R ₃	85.16	85.88	86.09	87.25	87.45	88.13
				Avg	85.31	86.03	86.25	87.06	87.57	87.91
			390	R ₁	85.52	85.92	86.50	86.92	87.19	88.60
				R ₂	85.77	86.49	87.00	87.45	87.74	87.64
				R ₃	85.76	86.34	86.87	87.65	88.25	88.16
				Avg	85.68	86.25	86.79	87.34	87.73	88.13
		170°C	330	R ₁	85.78	86.17	86.65	86.86	87.60	87.99
				R ₂	85.58	86.03	86.41	86.96	87.29	87.89
				R ₃	85.56	86.35	86.45	86.87	87.45	87.74

				Avg	85.64	86.18	86.51	86.90	87.44	87.87
			360	R ₁	85.95	86.19	86.54	86.70	87.20	88.05
				R ₂	85.72	86.38	86.73	86.90	87.67	87.69
				R ₃	85.74	86.18	86.43	87.16	87.49	88.06
				Avg	85.80	86.25	86.57	86.92	87.45	87.93
			390	R ₁	86.16	86.40	86.60	86.98	87.49	87.95
				R ₂	86.04	86.61	86.81	87.13	87.36	88.02
				R ₃	85.84	86.44	86.69	87.26	87.77	88.50
				Avg	86.01	86.48	86.70	87.12	87.54	88.16

Appendix C.II: Functional properties of extrudates

Sr. No	Nutritional properties	Temp	RPM	Replication	Treatment					
					T1	T2	T3	T4	T5	T6
1	Expansion ratio	130°C	330	R ₁	2.87	2.66	2.40	2.33	2.28	2.08
				R ₂	2.77	2.59	2.36	2.32	2.23	2.13
				R ₃	2.85	2.44	2.38	2.35	2.24	2.16
				Avg	2.83	2.56	2.38	2.33	2.25	2.12
			360	R ₁	2.99	2.93	2.69	2.27	1.93	2.41
				R ₂	3.02	2.89	2.71	2.15	1.98	2.42
				R ₃	3.00	2.96	2.67	2.16	1.99	2.38
				Avg	3.01	2.93	2.69	2.19	1.96	2.41
			390	R ₁	3.16	3.05	2.80	2.91	2.20	2.53
				R ₂	3.04	3.07	2.76	2.88	2.15	2.42
				R ₃	3.12	3.06	2.78	2.86	2.10	2.47
				Avg	3.11	3.06	2.78	2.88	2.15	2.47
		150°C	330	R ₁	3.39	2.94	3.07	2.66	2.37	2.71
				R ₂	3.37	2.98	2.96	2.64	2.36	2.68
				R ₃	3.32	3.07	2.92	2.61	2.33	2.73
				Avg	3.36	3.00	2.98	2.64	2.35	2.71
			360	R ₁	3.11	3.21	2.76	2.70	2.79	2.64

					R ₂	3.19	3.22	2.79	2.73	2.59	2.59
					R ₃	3.12	3.20	2.74	2.62	2.61	2.56
					Avg	3.14	3.21	2.76	2.68	2.66	2.60
					390	R ₁	3.34	3.31	3.08	2.46	2.39
						R ₂	3.37	3.14	2.93	2.56	2.39
						R ₃	3.36	3.13	3.00	2.44	2.35
						Avg	3.36	3.20	3.00	2.49	2.35
			170°C	330	R ₁	2.71	2.90	3.01	2.86	2.90	3.55
					R ₂	2.32	2.92	2.83	2.93	2.93	2.86
					R ₃	2.37	2.94	2.78	2.89	3.07	2.84
					Avg	2.47	2.92	2.87	2.89	2.97	3.09
				360	R ₁	3.05	2.96	3.07	3.09	2.91	2.91
					R ₂	3.13	3.39	3.09	2.99	3.04	2.95
					R ₃	3.05	2.85	3.01	2.97	3.01	2.90
					Avg	3.08	3.07	3.05	3.02	2.99	2.92
				390	R ₁	2.92	3.15	3.13	2.90	2.68	2.93
					R ₂	3.01	3.07	3.05	2.91	2.75	2.94
					R ₃	2.86	3.13	3.02	2.88	2.62	2.86
					Avg	2.93	3.12	3.07	2.90	2.69	2.91
2	Bulk density (g/cm ³)	130°C	330	R ₁	0.29	0.37	0.31	0.39	0.57	0.57	0.57
				R ₂	0.33	0.27	0.41	0.37	0.40	0.40	0.54
				R ₃	0.23	0.30	0.34	0.38	0.42	0.42	0.56
				Avg	0.28	0.32	0.35	0.38	0.46	0.46	0.55
			360	R ₁	0.19	0.15	0.15	0.21	0.46	0.46	0.25
				R ₂	0.19	0.16	0.18	0.23	0.33	0.33	0.31
				R ₃	0.15	0.16	0.17	0.18	0.20	0.20	0.30
				Avg	0.18	0.16	0.17	0.21	0.33	0.33	0.29
			390	R ₁	0.17	0.18	0.16	0.14	0.47	0.47	0.33
				R ₂	0.18	0.15	0.21	0.13	0.38	0.38	0.24
				R ₃	0.15	0.19	0.16	0.25	0.51	0.51	0.30
				Avg	0.17	0.17	0.18	0.17	0.45	0.45	0.29

		150°C	330	R ₁	0.11	0.29	0.16	0.33	0.33	0.26
				R ₂	0.12	0.22	0.19	0.23	0.31	0.24
				R ₃	0.13	0.25	0.22	0.28	0.32	0.26
				Avg	0.12	0.25	0.19	0.28	0.32	0.25
			360	R ₁	0.22	0.17	0.13	0.23	0.19	0.21
				R ₂	0.15	0.11	0.23	0.15	0.30	0.27
				R ₃	0.17	0.18	0.15	0.28	0.22	0.23
				Avg	0.18	0.15	0.17	0.22	0.24	0.24
			390	R ₁	0.11	0.13	0.10	0.16	0.27	0.28
				R ₂	0.13	0.15	0.15	0.17	0.26	0.42
				R ₃	0.17	0.12	0.12	0.14	0.29	0.25
				Avg	0.14	0.14	0.12	0.16	0.27	0.31
		170°C	330	R ₁	0.24	0.14	0.18	0.10	0.17	0.13
				R ₂	0.18	0.15	0.23	0.17	0.24	0.16
				R ₃	0.17	0.15	0.24	0.11	0.24	0.21
				Avg	0.20	0.15	0.21	0.13	0.22	0.17
			360	R ₁	0.20	0.22	0.17	0.16	0.24	0.16
				R ₂	0.14	0.14	0.14	0.21	0.19	0.16
				R ₃	0.16	0.23	0.12	0.17	0.18	0.13
				Avg	0.17	0.20	0.14	0.18	0.20	0.15
			390	R ₁	0.22	0.15	0.17	0.21	0.21	0.18
				R ₂	0.19	0.19	0.19	0.18	0.27	0.19
				R ₃	0.20	0.17	0.19	0.17	0.23	0.22
				Avg	0.20	0.17	0.18	0.19	0.24	0.20
3	Water Absorption Index (g/g)	130°C	330	R ₁	4.40	4.20	5.60	5.00	4.80	5.00
				R ₂	4.60	4.30	5.50	4.80	4.80	4.80
				R ₃	4.60	4.20	5.40	4.60	4.80	4.80
				Avg	4.53	4.23	5.50	4.80	4.80	4.87
			360	R ₁	3.80	4.20	4.00	3.20	4.20	4.00
				R ₂	3.60	4.20	4.00	3.20	4.40	3.80
				R ₃	3.80	4.40	4.40	3.20	4.60	3.70

				Avg	3.73	4.27	4.13	3.20	4.40	3.83
				R ₁	3.80	4.20	4.20	4.40	5.00	3.80
				R ₂	3.80	4.40	4.20	4.60	4.80	3.20
				R ₃	3.60	4.20	4.20	4.20	4.60	3.60
				Avg	3.73	4.27	4.20	4.40	4.80	3.53
		150°C	330	R ₁	4.60	4.00	3.00	3.40	3.80	4.00
				R ₂	4.80	4.00	2.60	3.80	4.20	3.80
				R ₃	4.60	3.80	2.60	4.00	3.60	3.90
				Avg	4.67	3.93	2.73	3.73	3.87	3.90
			360	R ₁	4.80	4.00	4.00	6.60	4.60	3.60
				R ₂	5.20	4.20	4.00	5.60	4.80	3.80
				R ₃	4.80	4.80	4.40	5.40	4.80	4.00
				Avg	4.93	4.33	4.13	5.87	4.73	3.80
			390	R ₁	3.60	4.20	3.80	5.60	4.60	4.40
				R ₂	3.80	4.00	4.20	5.40	4.20	4.60
				R ₃	4.00	4.00	4.00	5.20	4.60	4.80
				Avg	3.80	4.07	4.00	5.40	4.47	4.60
		170°C	330	R ₁	5.20	3.80	2.80	5.20	4.00	4.20
				R ₂	5.00	4.00	3.20	5.00	4.40	4.40
				R ₃	4.80	4.20	3.00	4.60	4.20	4.60
				Avg	5.00	4.00	3.00	4.93	4.20	4.40
			360	R ₁	4.20	3.80	4.20	4.40	3.60	2.80
				R ₂	4.80	3.60	4.60	5.20	3.20	3.00
				R ₃	4.60	3.20	4.00	5.00	3.40	3.20
				Avg	4.53	3.53	4.27	4.87	3.40	3.00
			390	R ₁	2.80	4.80	4.20	4.60	5.20	4.60
				R ₂	3.20	4.20	4.40	4.80	4.80	4.80
				R ₃	3.00	4.60	4.60	5.00	5.00	5.20
				Avg	3.00	4.53	4.40	4.80	5.00	4.87
4	Water Solubility	130°C	330	R ₁	38.00	36.00	30.00	26.00	26.00	22.00
				R ₂	36.00	34.00	32.00	28.00	24.00	18.00

	Index (%)			R ₃	40.00	30.00	34.00	28.00	20.00	24.00
				Avg	38.00	33.33	32.00	27.33	23.33	21.33
			360	R ₁	36.00	34.00	30.00	28.00	22.00	20.00
				R ₂	38.00	32.00	32.00	24.00	24.00	18.00
				R ₃	36.00	30.00	26.00	26.00	16.00	22.00
				Avg	36.67	32.00	29.33	26.00	20.67	20.00
			390	R ₁	36.00	34.00	30.00	26.00	24.00	18.00
				R ₂	32.00	32.00	26.00	28.00	22.00	22.00
				R ₃	34.00	28.00	24.00	20.00	18.00	16.00
				Avg	34.00	31.33	26.67	24.67	21.33	18.67
		150°C	330	R ₁	40.00	36.00	30.00	28.00	22.00	18.00
				R ₂	36.00	30.00	32.00	26.00	18.00	20.00
				R ₃	34.00	32.00	28.00	22.00	24.00	14.00
				Avg	36.67	32.67	30.00	25.33	21.33	17.33
			360	R ₁	34.00	32.00	28.00	26.00	24.00	18.00
				R ₂	36.00	26.00	26.00	24.00	18.00	16.00
				R ₃	32.00	34.00	32.00	22.00	16.00	14.00
				Avg	34.00	30.67	28.67	24.00	19.33	16.00
			390	R ₁	34.00	32.00	22.00	24.00	22.00	16.00
				R ₂	32.00	30.00	26.00	22.00	14.00	12.00
				R ₃	28.00	26.00	24.00	18.00	16.00	22.00
				Avg	31.33	29.33	24.00	21.33	17.33	16.67
		170°C	330	R ₁	38.00	34.00	32.00	30.00	24.00	16.00
				R ₂	32.00	30.00	30.00	26.00	22.00	14.00
				R ₃	34.00	28.00	24.00	20.00	16.00	20.00
				Avg	34.67	30.67	28.67	25.33	20.67	16.67
			360	R ₁	30.00	28.00	28.00	26.00	22.00	20.00
				R ₂	32.00	26.00	24.00	22.00	18.00	16.00
				R ₃	36.00	30.00	28.00	20.00	16.00	12.00
				Avg	32.67	28.00	26.67	22.67	18.67	16.00
			390	R ₁	32.00	28.00	26.00	22.00	18.00	16.00

				R ₂	32.00	26.00	22.00	16.00	16.00	14.00
				R ₃	28.00	24.00	20.00	20.00	14.00	16.00
				Avg	30.67	26.00	22.67	19.33	16.00	15.33
5	Hardness (g)	130°C	330	R ₁	3290.00	8305.00	11900.00	15905.00	11520.00	30315.00
				R ₂	2230.00	3670.00	11912.00	18755.00	12470.00	21345.00
				R ₃	2835.00	6180.00	12740.00	19905.00	11845.00	28270.00
				Avg	2785.00	6051.67	12184.00	18188.33	11945.00	26643.33
			360	R ₁	2765.00	2140.00	1825.00	1280.00	8510.00	4820.00
				R ₂	2660.00	2735.00	1605.00	1680.00	7985.00	1705.00
				R ₃	3040.00	1585.00	2170.00	1725.00	9805.00	2845.00
				Avg	2821.67	2153.33	1866.67	1561.67	8766.67	3123.33
			390	R ₁	1380.00	1505.00	3695.00	2875.00	11660.00	14780.00
				R ₂	1010.00	940.00	2490.00	1735.00	15700.00	11135.00
				R ₃	850.00	1790.00	4435.00	2470.00	17395.00	19215.00
				Avg	1080.00	1411.67	3540.00	2360.00	14918.33	15043.33
		150°C	330	R ₁	2380.00	2580.00	1045.00	6590.00	6085.00	4475.00
				R ₂	1210.00	2665.00	2995.00	6565.00	10240.00	5745.00
				R ₃	1380.00	4825.00	2900.00	6360.00	6670.00	3250.00
				Avg	1656.67	3356.67	2313.33	6505.00	7665.00	4490.00
			360	R ₁	1755.00	1495.00	2595.00	1950.00	4650.00	10245.00
				R ₂	1860.00	1430.00	1510.00	2585.00	6845.00	8630.00
				R ₃	1785.00	825.00	3525.00	6615.00	3320.00	6895.00
				Avg	1800.00	1250.00	2543.33	3716.67	4938.33	8590.00
			390	R ₁	3100.00	2875.00	1305.00	1630.00	4230.00	15445.00
				R ₂	2230.00	1305.00	1120.00	2545.00	2465.00	11410.00
				R ₃	2245.00	2145.00	830.00	2630.00	3965.00	16415.00
				Avg	2525.00	2108.33	1085.00	2268.33	3553.33	14423.33
		170°C	330	R ₁	3270.00	2005.00	3205.00	3750.00	3945.00	3395.00
				R ₂	1550.00	1555.00	1765.00	2470.00	4980.00	3455.00
				R ₃	2955.00	2605.00	3560.00	1420.00	3255.00	2600.00
				Avg	2591.67	2055.00	2843.33	2546.67	4060.00	3150.00

6	Yellowness Index	130°C	360	R ₁	1875.00	1650.00	3510.00	2615.00	1795.00	4460.00
				R ₂	1520.00	2440.00	2555.00	3755.00	3685.00	3920.00
				R ₃	3300.00	1185.00	2365.00	2115.00	2655.00	3688.00
				Avg	2231.67	1758.33	2810.00	2828.33	2711.67	4022.67
			390	R ₁	2020.00	3115.00	3825.00	2115.00	4000.00	2550.00
				R ₂	1705.00	2320.00	2810.00	2904.00	2235.00	3270.00
				R ₃	2070.00	2035.00	2380.00	2295.00	5115.00	2440.00
				Avg	1931.67	2490.00	3005.00	2438.00	3783.33	2753.33
	Yellowness Index	130°C	330	R ₁	5.87	5.86	5.82	5.30	5.41	4.63
				R ₂	5.86	5.87	5.83	5.31	5.42	4.64
				R ₃	5.88	5.88	5.84	5.32	5.43	4.62
				Avg	5.87	5.87	5.83	5.31	5.42	4.63
			360	R ₁	5.32	4.71	4.61	5.49	5.54	4.56
				R ₂	5.33	4.72	4.63	5.50	5.53	4.57
				R ₃	5.34	4.70	4.62	5.51	5.52	4.58
				Avg	5.33	4.71	4.62	5.50	5.53	4.57
			390	R ₁	4.94	4.95	4.76	5.06	5.29	5.36
				R ₂	4.96	4.96	4.74	5.04	5.28	5.37
				R ₃	4.95	4.98	4.75	5.05	5.27	5.38
				Avg	4.95	4.96	4.75	5.05	5.28	5.37
		150°C	330	R ₁	5.06	5.48	4.83	4.52	4.62	4.56
				R ₂	5.05	4.50	4.85	4.54	4.64	4.58
				R ₃	5.07	5.49	4.84	4.53	4.63	4.57
				Avg	5.06	5.16	4.84	4.53	4.63	4.57
			360	R ₁	5.74	5.31	5.18	5.51	4.55	4.57
				R ₂	5.76	5.30	5.20	5.49	4.54	4.56
				R ₃	5.75	5.32	5.19	5.50	4.56	4.55
				Avg	5.75	5.31	5.19	5.50	4.55	4.56
			390	R ₁	4.78	4.87	4.52	4.90	4.69	4.50
				R ₂	4.80	4.88	4.54	4.88	4.70	4.52
				R ₃	4.79	4.89	4.53	4.89	4.68	4.51

				Avg	4.79	4.88	4.53	4.89	4.69	4.51
		170°C	330	R ₁	5.46	5.02	5.09	4.74	4.52	4.96
				R ₂	5.49	5.01	5.10	4.75	4.53	4.97
				R ₃	5.47	4.90	5.11	4.76	4.54	4.98
				Avg	5.47	4.98	5.10	4.75	4.53	4.97
			360	R ₁	5.14	4.50	4.95	5.18	4.86	4.77
				R ₂	5.15	4.51	4.96	5.19	4.87	4.78
				R ₃	5.16	4.52	4.97	5.20	4.88	4.79
				Avg	5.15	4.51	4.96	5.19	4.87	4.78
			390	R ₁	5.49	4.63	5.36	5.02	4.90	4.93
				R ₂	5.50	4.64	5.37	5.03	4.91	4.94
				R ₃	5.51	4.65	5.38	5.04	4.92	4.95
				Avg	5.50	4.64	5.37	5.03	4.91	4.94

APPENDIX D

Appendix D: SENSORY EVALUATION SCORE SHEET

Name of Product:			
Date of Test:		Time:	
Age:		Sex:	

Rating for Score:

Sr. No.	Attribute	Score/ Mark
1	Extremely like	9
2	Very much like	8
3	Moderately like	7
4	Slightly like	6
5	Not like nor dislike	5
6	Slightly dislike	4
7	Moderately dislike	3
8	Very much dislike	2
9	Extremely dislike	1

Organoleptic Test:

Sample	Sensory Parameters							
Code	Appearance	Colour	Taste	Texture	Crispiness	Expansion	Overall	Remarks

	(9)	(9)	(9)	(9)	(9)	(9)	Acceptability (9)	
A								
B								
C								
D								
E								
F								
G								
H								
I								
J								
K								
L								
M								
N								
O								
P								
Q								
R								
S								
T								
U								
V								
W								
X								

Y								
Z								
A1								
B1								
C1								
D1								
E1								
F1								
G1								
H1								
I1								
J1								
K1								
L1								
M1								
N1								
O1								
P1								
Q1								
R1								
S1								
T1								
U1								
V1								
W1								
X1								

Y1								
Z1								
A11								
B11								
C11								

Remarks:

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Signature & Name

APPENDIX E

Appendix E: Sensory Evaluation of Tuber of the Tuber crops extrudates

Sample Code	Flour composition (Arrowroot: Lesser Yam: Potato)	Temperature, °C	RPM of Screw	Sensory Parameters						
				Appearance	Colour	Taste	Texture	Crispiness	Expansion	Overall Acceptability
A	0:50:50	130	330	6.5	6.4	6.1	6.5	6.6	6.6	6.5
B	10:40:50	130	330	6.1	6.1	6.2	6.2	6.4	6.5	6.3
C	20:30:50	130	330	6.4	6.3	6.3	6.4	6.6	6.7	6.5
D	30:20:50	130	330	6.5	6.5	6.6	6.5	6.5	6.4	6.5
E	40:10:50	130	330	6.1	6.2	6.4	6.3	6.3	6.4	6.3
F	50:0:50	130	330	6.4	6.4	6.3	6.3	6.4	6.2	6.3
G	0:50:50	130	360	6.4	6.1	6.0	6.2	6.1	6.2	6.2
H	10:40:50	130	360	6.5	6.2	6.1	6.3	6.3	6.3	6.3
I	20:30:50	130	360	7.5	7.5	6.9	7.4	7.1	7.0	7.2
J	30:20:50	130	360	7.5	7.4	6.7	7.4	6.8	6.5	7.0
K	40:10:50	130	360	6.5	7.5	7.3	7.1	7.4	7.4	7.2

Sample Code	Flour composition (Arrowroot: Lesser Yam: Potato)	Temperature, °C	RPM of Screw	Sensory Parameters						
				Appearance	Colour	Taste	Texture	Crispiness	Expansion	Overall Acceptability
L	50:0:50	130	360	7.6	7.4	7.2	7.5	7.1	7.3	7.4
M	0:50:50	130	390	7.3	7.7	7.4	7.3	7.3	7.4	7.4
N	10:40:50	130	390	7.5	7.2	8.5	7.4	7.0	7.3	7.5
O	20:30:50	130	390	7.3	7.6	7.4	7.4	7.2	7.3	7.4
P	30:20:50	130	390	6.9	7.5	7.0	7.3	7.5	7.5	7.3
Q	40:10:50	130	390	7.5	7.5	7.0	7.6	7.0	7.1	7.3
R	50:0:50	130	390	7.1	7.5	7.4	7.2	7.4	7.5	7.3
S	0:50:50	150	330	5.8	5.6	6.3	8.0	6.5	6.4	6.4
T	10:40:50	150	330	6.2	5.7	6.1	6.3	5.7	6.4	6.1
U	20:30:50	150	330	5.9	6.1	6.0	6.5	7.3	6.8	6.4
V	30:20:50	150	330	6.0	6.5	7.0	6.7	6.4	7.3	6.7
W	40:10:50	150	330	5.6	5.9	6.1	8.0	6.4	6.8	6.5
X	50:0:50	150	330	6.1	6.6	7.3	6.8	6.6	7.0	6.7
Y	0:50:50	150	360	5.8	5.9	6.2	6.2	6.7	6.9	6.3
Z	10:40:50	150	360	6.0	6.3	6.5	6.6	7.0	7.3	6.6
A1	20:30:50	150	360	6.5	6.2	6.5	6.5	6.4	6.2	6.4

Sample Code	Flour composition (Arrowroot: Lesser Yam: Potato)	Temperature, °C	RPM of Screw	Sensory Parameters						
				Appearance	Colour	Taste	Texture	Crispiness	Expansion	Overall Acceptability
B1	30:20:50	150	360	7.0	6.7	6.8	6.6	6.7	6.8	6.8
C1	40:10:50	150	360	5.3	5.8	6.2	6.5	6.4	6.6	6.1
D1	50:0:50	150	360	5.4	5.9	6.5	6.6	6.5	5.6	6.1
E1	0:50:50	150	390	7.1	7.8	6.8	7.3	6.9	7.3	7.2
F1	10:40:50	150	390	7.4	7.4	6.7	7.5	7.0	7.0	7.2
G1	20:30:50	150	390	6.9	7.4	6.8	6.9	7.3	7.5	7.1
H1	30:20:50	150	390	6.7	6.3	7.4	7.3	7.1	7.0	6.9
I1	40:10:50	150	390	6.8	6.3	7.3	7.1	7.0	7.0	7.0
J1	50:0:50	150	390	6.7	6.2	7.2	7.0	7.0	7.0	6.9
K1	0:50:50	170	330	6.2	5.7	5.8	6.3	6.6	6.6	6.2
L1	10:40:50	170	330	6.2	6.3	7.7	6.4	6.2	6.4	6.5
M1	20:30:50	170	330	6.7	6.6	6.4	6.5	6.5	6.4	6.5
N1	30:20:50	170	330	6.9	6.7	6.5	6.7	6.5	6.6	6.6
O1	40:10:50	170	330	6.7	6.5	6.4	6.5	6.7	6.5	6.6
P1	50:0:50	170	330	6.4	6.2	6.2	6.2	6.1	6.5	6.3
Q1	0:50:50	170	360	7.0	6.0	6.5	6.6	7.0	6.9	6.7

Sample Code	Flour composition (Arrowroot: Lesser Yam: Potato)	Temperature, °C	RPM of Screw	Sensory Parameters						
				Appearance	Colour	Taste	Texture	Crispiness	Expansion	Overall Acceptability
R1	10:40:50	170	360	6.5	6.5	6.8	6.7	6.4	6.8	6.6
S1	20:30:50	170	360	5.7	6.4	6.4	6.7	5.9	6.7	6.3
T1	30:20:50	170	360	6.6	6.5	5.7	6.8	7.7	7.4	6.8
U1	40:10:50	170	360	5.7	5.9	6.5	6.2	6.5	6.9	6.3
V1	50:0:50	170	360	6.5	6.1	6.5	6.7	6.5	7.0	6.5
W1	0:50:50	170	390	6.5	8.3	7.2	7.3	6.6	7.4	7.2
X1	10:40:50	170	390	6.0	6.5	6.5	6.8	7.0	7.1	6.6
Y1	20:30:50	170	390	6.1	6.3	6.5	6.5	6.8	7.0	6.6
Z1	30:20:50	170	390	6.0	5.9	6.4	7.0	7.3	7.4	6.7
A11	40:10:50	170	390	7.5	7.2	6.7	7.4	6.9	7.2	7.1
B11	50:0:50	170	390	7.5	7.3	6.7	7.4	6.9	7.0	7.1
C11	CONTROL			7.2	6.9	6.8	7.1	6.9	6.4	6.9

APPENDIX F

Appendix F: Nutritional and Functional Properties of Storage study

Appendix F.I: Nutritional Properties of Storage study

Sr. No.	Days	Replications	Polyethylene					
			Protein (%)	Fat (%)	Fiber (%)	Ash (%)	Moisture (%)	Carbohydrates (%)
1	0	R1	2.98	1.42	1.20	2.00	6.65	85.76
		R2	2.80	1.43	1.22	1.95	6.65	85.95
		R3	2.98	1.41	1.27	2.00	6.65	85.70
		Avg.	2.92	1.42	1.23	1.98	6.65	85.80
2	10	R1	2.80	1.40	1.20	1.95	6.70	85.95
		R2	2.63	1.39	1.22	1.95	6.68	86.14
		R3	2.98	1.36	1.19	1.94	6.67	85.87
		Avg.	2.80	1.38	1.20	1.95	6.68	85.98
3	20	R1	2.98	1.43	1.19	1.96	6.69	85.76
		R2	2.63	1.44	1.20	1.93	6.70	86.11
		R3	2.63	1.20	1.12	1.87	6.74	86.45
		Avg.	2.74	1.36	1.17	1.92	6.71	86.10
4	30	R1	2.63	1.27	1.12	1.93	6.75	86.31
		R2	2.45	1.30	1.15	1.93	6.70	86.47
		R3	2.80	1.40	1.15	1.81	6.79	86.05
		Avg.	2.63	1.32	1.14	1.89	6.75	86.28
5	40	R1	2.63	1.30	1.14	1.90	6.78	86.26
		R2	2.63	1.20	1.10	1.85	6.79	86.44
		R3	2.45	1.27	1.09	1.79	6.84	86.56
		Avg.	2.57	1.26	1.11	1.85	6.80	86.42
6	50	R1	2.63	1.28	1.11	1.84	6.81	86.34
		R2	2.28	1.35	1.06	1.81	6.78	86.73
		R3	2.63	1.00	1.01	1.77	6.95	86.65

		Avg.	2.51	1.21	1.06	1.81	6.85	86.57
7	60	R1	2.63	1.00	1.01	1.82	6.95	86.60
		R2	2.45	1.19	1.11	1.76	6.78	86.71
		R3	2.28	1.26	0.95	1.73	6.89	86.90
		Avg.	2.45	1.15	1.02	1.77	6.87	86.73
	Days	Replications	Polyester					
			Protein (%)	Fat (%)	Fiber (%)	Ash (%)	Moisture (%)	Carbohydrates (%)
8	0	R1	2.98	1.42	1.20	2.00	6.65	85.76
		R2	2.98	1.43	1.22	1.95	6.65	85.78
		R3	2.98	1.41	1.27	2.00	6.65	85.70
		Avg.	2.98	1.42	1.23	1.98	6.65	85.74
9	10	R1	2.98	1.40	1.22	1.93	6.67	85.81
		R2	2.80	1.40	1.20	1.95	6.69	85.96
		R3	2.71	1.40	1.22	2.00	6.65	86.02
		Avg.	2.83	1.40	1.21	1.96	6.67	85.93
10	20	R1	2.80	1.30	1.17	1.93	6.70	86.10
		R2	2.63	1.40	1.23	1.90	6.78	86.07
		R3	3.01	1.41	1.17	2.00	6.58	85.83
		Avg.	2.81	1.37	1.19	1.94	6.69	86.00
11	30	R1	2.80	1.30	1.13	1.92	6.89	85.96
		R2	2.63	1.32	1.24	1.89	6.65	86.28
		R3	2.89	1.41	1.10	1.89	6.60	86.11
		Avg.	2.77	1.34	1.16	1.90	6.71	86.12
12	40	R1	2.63	1.32	1.16	1.89	6.78	86.23
		R2	2.45	1.27	1.09	1.86	6.83	86.50
		R3	2.84	1.30	1.13	1.88	6.77	86.09
		Avg.	2.64	1.30	1.13	1.88	6.79	86.27
13	50	R1	2.80	1.28	1.09	1.84	6.78	86.21
		R2	2.45	1.32	1.11	1.82	6.88	86.42
		R3	2.54	1.21	1.08	1.85	6.81	86.51
		Avg.	2.60	1.27	1.09	1.84	6.82	86.38
14	60	R1	2.80	1.20	1.01	1.82	6.91	86.26
		R2	2.63	1.13	1.10	1.88	6.88	86.39
		R3	2.28	1.23	1.03	1.71	6.74	87.02

		Avg.	2.57	1.19	1.05	1.80	6.84	86.55
	Days	Replications	Aluminium foil					
			Protein (%)	Fat (%)	Fiber (%)	Ash (%)	Moisture (%)	Carbohydrates (%)
15	0	R1	2.98	1.42	1.20	2.00	6.65	85.76
		R2	2.80	1.43	1.22	1.95	6.65	85.95
		R3	2.98	1.41	1.27	2.00	6.65	85.70
		Avg.	2.92	1.42	1.23	1.98	6.65	85.80
16	10	R1	2.98	1.41	1.19	1.93	6.69	85.81
		R2	2.98	1.40	1.21	1.99	6.63	85.80
		R3	2.63	1.41	1.27	2.00	6.68	86.02
		Avg.	2.86	1.41	1.22	1.97	6.67	85.87
17	20	R1	2.94	1.34	1.19	1.93	6.68	85.92
		R2	2.98	1.43	1.20	1.95	6.69	85.76
		R3	2.59	1.40	1.22	1.98	6.66	86.15
		Avg.	2.84	1.39	1.20	1.95	6.68	85.94
18	30	R1	2.98	1.34	1.18	1.94	6.64	85.93
		R2	2.63	1.37	1.16	1.92	6.67	86.26
		R3	2.80	1.34	1.20	1.91	6.78	85.97
		Avg.	2.80	1.35	1.18	1.92	6.70	86.05
19	40	R1	2.80	1.33	1.17	1.92	6.65	86.13
		R2	2.45	1.20	1.10	1.93	6.78	86.54
		R3	2.98	1.46	1.19	1.86	6.76	85.76
		Avg.	2.74	1.33	1.15	1.90	6.73	86.14
20	50	R1	2.94	1.38	1.17	1.93	6.78	85.80
		R2	2.71	1.33	1.16	1.89	6.75	86.16
		R3	2.45	1.15	1.00	1.79	6.87	86.74
		Avg.	2.70	1.29	1.11	1.87	6.80	86.23
21	60	R1	2.98	1.33	1.20	1.89	6.78	85.83
		R2	2.80	1.20	1.22	1.76	6.87	86.15
		R3	2.98	1.11	1.27	1.82	6.77	86.06
		Avg.	2.92	1.21	1.23	1.82	6.81	86.01

Appendix F.II: Functional Properties of Storage study

Sr. No	Days	Replications	Polyethylene					Polyester					Aluminium foil				
			Hardness (g)	Water absorption index (g/g)	Water solubility index (%)	Bulk density (g/cm ³)	Expansion ratio	Hardness (g)	Water absorption index (g/g)	Water solubility index (%)	Bulk density (g/cm ³)	Expansion ratio	Hardness (g)	Water absorption index (g/g)	Water solubility index (%)	Bulk density (g/cm ³)	Expansion ratio
1	0	R1	1505	4.20	34.00	0.18	3.05	1505	4.20	34.00	0.18	3.05	1505	4.20	34.00	0.18	3.05
		R2	940	4.40	32.00	0.15	3.07	940	4.40	32.00	0.15	3.07	940	4.40	32.00	0.15	3.07
		R3	1790	4.20	28.00	0.19	3.06	1790	4.20	28.00	0.19	3.06	1790	4.20	28.00	0.19	3.06
		Avg.	1411	4.27	31.33	0.17	3.06	1411	4.27	31.33	0.17	3.06	1411	4.27	31.33	0.17	3.06
2	10	R1	1600	4.27	34.00	0.15	3.05	1372	4.29	35.00	0.17	3.06	1360	4.22	31.00	0.17	3.09
		R2	1000	4.30	34.00	0.14	3.08	1576	4.38	33.00	0.15	3.09	1456	4.32	33.00	0.16	3.08
		R3	1790	4.42	32.00	0.14	3.09	1387	4.27	30.00	0.14	3.04	1495	4.31	32.00	0.14	3.08
		Avg.	1463	4.33	33.33	0.14	3.07	1445	4.31	32.67	0.15	3.06	1437	4.28	32.00	0.16	3.08
3	20	R1	1620	4.32	34.00	0.17	3.08	1436	4.30	36.00	0.16	3.09	1478	4.37	33.00	0.17	3.09
		R2	1206	4.30	35.00	0.11	3.09	1574	4.44	33.00	0.15	3.07	1324	4.35	37.00	0.16	3.10
		R3	1800	4.47	36.00	0.10	3.09	1459	4.27	33.00	0.12	3.05	1595	4.23	29.00	0.14	3.09
		Avg.	1542	4.36	35.00	0.13	3.09	1489	4.34	34.00	0.14	3.07	1465	4.32	33.00	0.16	3.09
4	30	R1	1708	4.45	35.00	0.10	3.04	1657	4.36	35.00	0.15	3.09	1474	4.30	39.00	0.12	3.06
		R2	1400	4.47	38.00	0.12	3.05	1337	4.44	38.00	0.12	3.06	1479	4.38	36.00	0.14	3.07
		R3	1587	4.39	38.00	0.13	3.08	1632	4.37	37.00	0.11	3.09	1644	4.40	32.00	0.15	3.05
		Avg.	1565	4.44	37.00	0.12	3.06	154	4.39	36.67	0.13	3.08	1532	4.36	35.67	0.14	3.06
5	40	R1	1890	4.48	38.00	0.10	3.09	1547	4.36	36.00	0.13	3.10	1465	4.40	38.00	0.14	3.08
		R2	1467	4.49	39.00	0.08	3.10	1476	4.53	39.00	0.11	3.09	1586	4.38	37.00	0.11	3.07
		R3	1589	4.54	41.00	0.10	3.06	1678	4.49	40.00	0.12	3.05	1593	4.50	38.00	0.12	3.07
		Avg.	1648	4.50	39.33	0.09	3.08	1567	4.46	38.33	0.12	3.08	1548	4.43	37.67	0.12	3.07
6	50	R1	1496	4.56	42.00	0.10	3.07	1549	4.40	39.00	0.11	3.09	1533	4.53	37.00	0.16	3.08
		R2	1894	4.48	43.00	0.08	3.08	1747	4.60	42.00	0.11	3.08	1600	4.51	39.00	0.10	3.07
		R3	1674	4.54	42.00	0.09	3.06	1658	4.54	44.00	0.11	3.10	1768	4.40	43.00	0.07	3.09
		Avg.	1688	4.53	42.33	0.09	3.07	1651	4.51	41.67	0.11	3.09	1633	4.48	39.67	0.11	3.08
7	60	R1	1980	4.46	44.00	0.10	3.09	1674	4.56	45.00	0.10	3.05	1634	4.50	40.00	0.10	3.09
		R2	1880	4.65	45.00	0.06	3.10	1584	4.53	41.00	0.10	3.07	1687	4.56	43.00	0.11	3.08
		R3	1309	4.66	42.00	0.08	3.07	1823	4.60	43.00	0.10	3.06	1654	4.55	45.00	0.06	3.10
		Avg.	1723	4.59	43.67	0.08	3.09	1693	4.56	43.00	0.10	3.06	1658	4.54	42.67	0.09	3.09

